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OF THE

American Institute of Electrical Engineers

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Number 1

JANUARY, 1919

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TABLE OF CONTENTS

Section I.—Institute Affairs

A. I. E. E. Meeting in New York, January 10, 1919 1
A. I. E. E. Midwinter Convention, February 19-21, 1919 1
Future Section Meetings 1
A. I. E. E. Directors Meeting, Philadelphia, December 18, 1918 2
Nominations for Institute Officers for 1919-20 2
A. I. E. E. Meeting in Philadelphia 3
American Engineers Go to France 4
Field of Activity of Engineering Council 4
Past Section Meetings 5
Associates Elected December 18, 1918 6
Associates Re-elected December 18, 1918 8
Members Elected 8
Fellows Elected 8
Transferred to Grade of Fellow December 18, 1918 8
Transferred to Grade of Member December 18, 1918 8
Recommended for Transfer 9
Applications for Election 9
Students Enrolled 11
Addresses Wanted 11
Personal 12
Obituary 12
Employment Service 13
Engineering Service Bulletin 14
Accessions to the Engineering Societies Library 18
Honor Roll 21

Section II.—Papers and Reports

Review of Work of Sub-Committee on Wave Shape Standard of the Standards Committee. By Harold S. Osborne, New York, February 20, 1919 1
Electric Power Generation in Ontario on Systems of Hydroelectric Power Commission. By Arthur H. Hull, Toronto, Canada, November 22, 1918 29

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ESTABLISHED 1884

PROCEEDINGS

Vol. XXXVIII JANUARY, 1919 Number 1

A. I. E. E. MEETING IN NEW YORK, JANUARY 10, 1919

The 345th meeting of the American Institute of Electrical Engineers will be held on Friday evening, January 10, 1919, in the Auditorium of the Engineering Societies Building, 33 West 39th Street, New York, at 8:30 p. m. The subject of the meeting will be "Aeronautics," and a lecture will be given by Major General George O. Squier, Chief Signal Officer of the United States Army on "Aeronautics in the United States." The lecture will include the developments in this field from the beginning of the war down to the present time and will be illustrated by moving pictures showing details of the processes of manufacturing airplanes and accessories. There will also be displayed several groups of models of certain equipment which has been developed by the Signal Corps during the period of the war.

Non-members of the Institute who are interested in this subject, including ladies, are cordially invited to attend this lecture.

A. I. E. E. MIDWINTER CONVENTION FEBRUARY 19-21, 1919

The Seventh Annual Midwinter Convention of the American Institute of Electrical Engineers will be held at the Institute headquarters, 33 West 39th Street, New York, February 19, 20 and 21, 1919. While the complete details of the program have not yet been completed the tentative arrangements may be described as follows:

On Wednesday afternoon there will be a joint meeting with the American Institute of Mining Engineers at which several papers on Electric Welding will be presented.

On Wednesday evening there will be a popular lecture with moving pictures which were adopted by the U. S. Government for the instruction of troops in regard to various mechanical and engineering processes.

On Thursday morning there will be a technical session opened with an address by President Adams.

Thursday afternoon has been reserved for trips of engineering interest to points in and about New York, and Thursday evening there will be a reception and dance at the Institute headquarters.

On Friday morning there will be a technical session under the auspices of the Electrophysics Committee, and the last session of the convention will be on Friday afternoon at which several papers under the auspices of the Telegraphy and Telephony Committee will be presented.

The complete program will be published in the February issue of the PROCEEDINGS.

FUTURE SECTION MEETINGS

Baltimore.—January 10, 1919. Subject: "Ship Propulsion."

Boston.—January 7, 1919, Chipman Hall, Tremont Temple. Subject: "The Principles of Camouflage for Land, Sea, and Air. Speaker: M. Luckiesh.

Philadelphia.—January 15, 1919, Engineers' Club. Subject: "Lighting in War Times." Speaker: Preston S. Millar.

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Schenectady.—January 17, 1919. Subject: "Features of Design and Operation of the Turners Falls Power & Electric Company." Speaker: F. L. Hunt.

Washington.—January 14, 1919. Subject: The Electrification of the Chicago, St. Paul and Milwaukee Railway. Speaker: N. W. Storer.

A. I. E. E. DIRECTORS' MEETING PHILADELPHIA, DECEMBER 13, 1918

The regular monthly meeting of the Board of Directors was held at the Bellevue-Stratford Hotel, Philadelphia, on Friday, December 13, 1918, at 10:30 a. m.

There were present: President C. A. Adams, Cambridge, Mass.; Vice-Presidents F. B. Jewett, New York, and John B. Taylor, Schenectady; Managers C. E. Skinner, Charles Robbins, and Frank D. Newbury, Pittsburgh, N. A. Carle, Newark, N. J., Walter A. Hall, Lynn, Mass., Wm. A. Del Mar and W. I. Slichter, New York; Treasurer George A. Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

The action of the Finance Committee in approving monthly bills amounting to $8557.03, was ratified.

Chairman Slichter of the Meetings and Papers Committee reported upon plans for coming Institute meetings, including the Midwinter Convention, February 19, 20, and 21, as referred to elsewhere in this issue.

A report of the meeting of the Board of Examiners held November 25 was presented; and the actions taken at this meeting were approved.

In accordance with the recommendations of the Board of Examiners the following action was taken upon pending applications: 5 students were ordered enrolled; 54 applicants were elected to the grade of Associate; 3 applicants were re-elected to the grade of Associate; 6 applicants were elected to the grade of Member; 1 applicant was elected to the grade of Fellow; 13 applicants were transferred to the grade of Member; and 2 applicants were transferred to the grade of Fellow.

Announcement was made that in accordance with the by-laws of the Institute President Comfort A. Adams will become a member of the John Fritz Medal Board of Award for a term of four years beginning on the third Friday in January.

A considerable amount of other business was transacted by the Board, reference to which will be found in this and future issues of the PROCEEDINGS.

NOMINATIONS FOR INSTITUTE OFFICERS FOR 1919-20

As provided in Section 20 of the Institute by-laws, candidates may now be proposed for nomination for the offices to be filled at the next annual election in May, 1919, by the petition or by the separate endorsement in writing, of not less than fifty members. The petitions or separate endorsements must be in the hands of the Secretary not later than January 25, 1919. For the convenience of members, a form of petition has been prepared by the Secretary, and copies of it may be obtained upon application to Institute headquarters. Endorsements may, however, be made by letter if the form is not available. A member is not limited in the number of candidates he may endorse in this manner.

The officers to be elected are: a President and a Treasurer, for the term of one year each, six Vice-Presidents for the term of one year each, and three Managers for the term of four years each.

The Constitution provides that "the President, Vice-Presidents and Managers shall not be eligible for immediate reelection to the same office. A Vice-President shall not be eligible for immediate election to the office of Manager."

For the information of members, the full text of Section 20 of the by-laws, governing the proposal of candidates for nomination, is printed below:

Sec. 20. In addition to the names of incumbents of office, the Secretary shall publish on the "form showing offices to be filled at the ensuing annual election in May" provided for in Article VI of the Constitution, the names, as candidates for nomination, of such members of the INSTITUTE as have been proposed for nomination for a particular office by the petition or by the separate endorsement of not less than fifty members, received by the Secretary of the INSTITUTE in writing by January 25 of each year.

The names of such candidates for nomination shall be grouped alphabetically under the name of the office for which each is proposed, and this by-law shall be reprinted prominently in the December and January issue of each year's PROCEEDINGS, and shall be reproduced on the form above referred to.

A. I. E. E. MEETING IN PHILADELPHIA

The 342nd meeting of the American Institute of Electrical Engineers was held in the Bellevue Stratford Hotel, Philadelphia, December 13, 1918, under the auspices of the Philadelphia Section.

The total attendance at the meeting was 230 including Institute members and visitors. The meeting consisted of an afternoon and evening session with an informal dinner between the sessions. The papers for the afternoon session were provided under the auspices of the Committee on Mines and were as follows:

"The Use of Electric Power in the Mining of Anthracite Coal," by J. B. Crane.

"Drum Shape as Affecting the Mine Hoist Duty Cycle," by F. L. Stone.

The meeting was opened at 2:30 o'clock p. m. and was called to order by Mr. W. F. James, Chairman of the Philadelphia Section, who after a few remarks of welcome turned the meeting over to President C. A. Adams. President Adams called on Mr. Crane who abstracted his paper and was followed by Mr. Stone who also presented his paper in abstract. The two papers were discussed together and the discussion brought out that the Coal Administration has arranged for redistribution of excess station power to coal mines needing the supply and that much work has been done along this line to the advantage of both mine operators and power stations. On the subject of speeds of hoists as affected by the method of elevation it was pointed out that the best practise tended towards slower speeds and the use of large skips for handling coal in considerable quantities.

The informal dinner between sessions was held at 6:00 o'clock on the roof garden of the Bellevue Stratford with 130 members in attendance.

The evening session was called to order by President Adams, who presented the first speaker of the evening, Dr. W. R. Whitney, who gave an address on "American Engineering Research." Dr. Whitney was followed by Colonel R. A. Millikan who spoke on the subject of "Engineering Research After the War." Both of these addresses will be printed in a future issue of the PROCEEDINGS. There was a general discussion following these addresses which emphasized the lack of publicity agencies in regard to the appreciation of the relatively poor standing of scientific research in the United States, and the necessity of financial support of research work in the universities of the country if the United States is to take a proper place among the nations in scientific development. It was pointed out that financial support in the case of agricultural research had put this country among the first along these lines and similar assistance should also prove of equal value in stimulating scientific research.

The technical excursion past the shipyards down the Delaware River planned for Saturday morning had to be abandoned on account of the heavy fog that prevailed, but about 50 of the members took advantage of the opportunity to visit the Chester generating station of the Beacon Light Company (Philadelphia Electric Company) which is in process of construction. One 30,000 kw. generator set is in operation and a second one almost completed. The ultimate capacity of this station, which is a handsome piece of archi-

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tecture, will be four of these units. A bank of two boilers is provided for each turbine unit and one of the special features of this installation is the indicator panel and control board for these boilers. After completing the inspection of the plant the visitors were entertained at luncheon by the Philadelphia Electric Company.

AMERICAN ENGINEERS GO TO FRANCE

At the invitation of the French Society of Civil Engineers and a committee of the French Engineers' Congress, and with the official approval of the French government, a delegation of American engineers has been appointed to study with French engineers certain problems involved in the industrial rehabilitation of France after the war.

This delegation was invited to go to Paris to examine in joint conference questions of the utilization of commercial ports, the development of navigable waterways, the development of water power and the improvement of road systems. Although these were the only subjects mentioned specifically, the congress will probably take up many other questions of development in which all engineers are directly interested.

The invitation was sent to the American Society of Civil Engineers and was accepted at once by cable, the acceptance stating that such a delegation would be organized in cooperation with the other American national societies.

The Executive Committee of the American Institute of Electrical Engineers selected Mr. Lewis B. Stillwell, Consulting Engineer, 100 Broadway, New York, as a representative upon this delegation.

The complete delegation, which sailed from New York December 5 on the steamer Espagne, is as follows: Messrs. James F. Case, Chairman, George W. Fuller, A. M. Hunt, Nelson P. Lewis, Charles T. Main, E. Gybbon Spilsbury, Lewis B. Stillwell, George F. Swain, and George W. Tillson.

FIELD OF ACTIVITY OF ENGINEERING COUNCIL

Engineering Council held its organization meeting June 27, 1917, in Engineering Societies Building, New York. A remarkable period has since passed in the history of the country and the engineering profession. Created under By-Laws of United Engineering Society granting broad powers, Council has refrained from defining its field of activity until it had experience to guide it. This course has been the more necessary because of the unusual conditions. At a special meeting held November 21, 1918, at which a number of interesting and important actions were taken, the following resolutions were adopted:

WHEREAS, United Engineering Society has, in accordance with the desires of the four Founder Societies (American Society of Civil Engineers, American Institute of Mining Engineers, American Society of Mechanical Engineers, American Institute of Electrical Engineers), established a department, "in addition to its other activities and entirely separate therefrom," "known as the Engineering Council," (preamble to By-Laws 114 to 124); and

WHEREAS, provision has been made for the admission of "other national engineering or technical societies," (By-Law 123); and

WHEREAS, the By-Laws of United Engineering Society stipulate that Engineering Council is to provide for convenient cooperation between Engineering Societies, "for the proper consideration of questions of general interest to engineers and to the public, and to provide the means for united action upon questions of common concern to engineers," and that "Council may speak authoritatively for all member societies on all public questions of common interest or concern to engineers, unless objection be made by a majority of the representatives present of one of the Founder Societies or by one-quarter of the representatives present and voting," (By-Laws, preamble and 116); be it

RESOLVED: That Engineering Council understands its field of activity to be approximately as follows.

(1) Council may deal with any matter of general interest for which joint action of two or more of its member societies would have been appropriate, if Council had not been established.

(2) Council may initiate and carry through projects of the general character defined in the

by-laws, for which the necessary financial provision has been made; but Council shall not undertake expenditures in excess of appropriations for its uses made by United Engineering Society on behalf of the Founder Societies and the contributions from other member societies, unless specific provision shall have been made therefor by subscription, donation or otherwise; moneys received by Engineering Council shall be turned into the treasury of United Engineering Society and disbursed by it, for the purposes designated.

(3) Council may take up, and in its discretion act upon, any matter of general interest referred to it by any member society or by any other society,—national, state or local,—or by any branch of Government, or by an individual or group of individuals.

Resolved: That Engineering Council will as a rule avoid considering any matter which is specifically within the province of only one member society and not of others.

PAST SECTION MEETINGS

Baltimore.—November 11, 1918, Engineers Club. Illustrated address by President C. A. Adams on "Application of Electric Welding to Ship Building." Attendance 100.

Boston.—December 3, 1918, Engineers Club. Illustrated address by Dr. Ellwood B. Spear on "Problems of Gas Warfare." Attendance 45.

Chicago.—November 25, 1918, Western Society of Engineers' Rooms. Papers: (1) "Lighting Curtailment" by Preston S. Millar; (2) "Conservation of Coal During War Times in the State of Illinois" by Harold Almert. Joint meeting of local engineering organizations. Attendance 225.

Cleveland.—November 19, 1918, Electrical League. Illustrated address by President C. A. Adams on "Electric Welding." Attendance 112.

Detroit—Ann Arbor.—December 13, 1918, Detroit Board of Commerce. Paper: "Fundamental Principles and Calculations of Direct-Current Circuits" by John C. Parker. Attendance 30.

Fort Wayne.—November 21, 1918, Building 16, G. E. Co. Address by Capt. R. N. Vyvyan on "The Application of Wireless Telegraphy and Telephony to Aeroplane Work." Attendance 23.

Ithaca.—December 6, 1918, Franklin Hall, Cornell University. Address by Dr. Carl Hering on "Departures from the Beaten Track." Attendance 125.

Lynn.—November 20, 1918, General Electric Hall. Paper: "The Transformer Industry and Some of Its Problems" by Matthew O. Troy. Attendance 90.

Pittsburgh.—November 19, 1918, Auditorium, Chamber of Commerce. Paper: "New Locomotive and Substation Equipment for Chicago, Milwaukee and St. Paul R. R." by N. W. Storer. Attendance 135.

December 10, 1918, Chamber of Comermerce Auditorium. Paper: "The Power Developments at Niagara" by P. M. Lincoln. Attendance 75.

Pittsfield.—November 14, 1918, New American House. Address by Hon. Allen T. Treadway on "War Time Legislation." Informal talks by Messrs. F. R. Whittlesey, G. Faccioli, and M. O. Troy.

November 22, 1918, Masonic Temple. Illustrated lecture by Mr. William Henry Blood on "The Building of Hog Island Shipyard—A Great Achievement of a Great Epoch." Attendance 625.

December 5, 1918, New American Hotel. Illustrated lecture by President C. A. Adams on "Arc Welding as Applied to Ship Building." Mr. R. E. Wagner showed motion picture of a large electrically welded pressure tank while being subjected to a breathing test. Attendance 165.

Rochester.—November 29, 1918, Rochester Engineering Society. Address by Mr. E. S. Johnson on "The Chicago, Milwaukee and St. Paul Electrification." Attendance 60.

San Francisco.—December 6, 1918, Engineers' Club. Paper: "New Charts for the Ascertaining of Sag Constants in Aerial Suspension" by Joseph N. LeConte. Attendance 65.

Schenectady.—November 15, 1918, Edison Club Hall. Address by Dr.

Gulick on "Immigration." Attendance 200.

December 10, 1918, Edison Club Hall. Address by President C. A. Adams on "Electric Welding with Special Reference to Its Application to Ship Building." Attendance 345.

Seattle.—November 19, 1918, Chamber of Commerce. Paper: "A Basic Plan for the Development of our National Electric Power Resources." by C. E. Magnusson. Attendance 37.

St. Louis.—November 27, 1918, Engineers' Club. Address by Mr. E. E. Huffman on "United States Patent Law and Procedure." Attendance 25.

Toronto.—December 6, 1918, Toronto University. Illustrated lecture by Dr. Saul Dushman on "Modern Applications of the Electron Theory." Attendance 120.

Urbana.—November 20, 1918, Electrical Engineering Laboratory. Election of officers as follows—chairman, A. R. Knight; secretary-treasurer, E. H. Waldo; chairman membership committee, E. B. Paine.

ASSOCIATES ELECTED DECEMBER 13, 1918

ALWARD, ERNEST TURNBULL, Sales Engineer, Northern Electric Co.; res., 794 St. Urbain St., Montreal, Canada.

AMANO, SHIN-ICHI, Engineer, Ina-washiro Hydro-Electric Power Co., Bandai, Fuskushima-ken, Japan.

AUTY, CLARENCE, Designing, Testing, Mech & Elec. Engineering, John A. Stevens, 8 Merrimack St., Lowell; res., Andover, Mass.

BUCKLAND, BERT, Colliery Electrician, Bolsover Colliery Co.; res., 47 Shuttlewood Road, Bolsover, Chesterfield, Eng.

CAROTHERS, ROBERT M., Engineering Dept., General Electric Co.; res., 10 Elder St., Schenectady, N. Y.

CARSON, JAMES B., Draftsman, Oregon Short Line R. R., 606 Deseret News Bldg.; res., Commercial Club, Salt Lake City, Utah,

CLARK, JUDSON H., Distribution Department, Bureau of Power & Light, City of Los Angeles; res., 5928 S. Vermont Ave., Los Angeles, Cal.

CRABBE, GEORGE N., Engineer, Otis Elevator Co., 250 11th Ave., New York, N. Y.; res., Cresskill, N. J.

CRAHAN, BERNARD JAMES, General Manager, Port Huron Gas & Electric Co.; res., 917 Lincoln Ave., Port Huron, Mich.

CRESSEY, JOHN ALFRED, Power Station, Aerodrome, Sedgeford; res., Bobbers Mill, Nottingham, England.

DEANE, ALVA IRL, Plant Instructor, Central District Tel. Co.; res., 184 Sheridan St., Bellevue Sta., Pittsburgh, Pa.

DE SOUZA, DURVAL EGYDIO, Manager, Banco Construction do Brazil; res., Rua Ypiranga 1218, Petropolis, Brazil, S. A.

*DOUGLAS, JOHN ANDREW, Master Mechanic, 2nd Class, Officer's Material School, U. S. Navy; res., 109 St. Joseph St., Mobile, Ala.

EMERSON, RALPH MARTINDALE, Foreman, Electrical Repair Dept., Capital Electric Co.; res., 270 W. 2nd St., Salt Lake City, Utah.

ENNES, ALBERT W., Asst. Chief Electrician, Monarch Mills, N. Portland; res., 1690 E. 6th St., Portland, Ore.

*EWART, FRED E., Turbine Engg. Dept., General Electric Co.; res., 85 Garfield Ave., Lynn, Mass.

FISH, ALEXANDER HAMILTON, Erecting Engineer, Construction Dept., General Electric Co., Schenectady, N. Y.

FOOTE, JAMES HAROLD, Engineer, Construction Dept., Consumers Power Co.; res., 1512 W. Washington Ave., Jackson, Mich.

GLEASON, D. T., Asst. Chief Engineer, Standard Steel Spring Co.; res., 913 Fifth Ave., Corapolis, Pa.

HALL, J. B., Erecting Engineer, Construction Dept., General Electric Co., Schenectady, N. Y.

Hamlin, William M., Private, 24 Aero Squadron, American Air Service; res., Wautoma, Wis.

Heckman, August, Asst. to Works Electrical Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Heiser, Charles E., Asst. Electrical Engineer, Philadelphia & Reading Railway; res., Ideal Apts., 6th & Elm St., Reading, Pa.

Hight, William Russell, Asst. Engineer, Engineering Div., Sperry Gyroscope Co.; res., 210 Hicks St., Brooklyn, N. Y.

Hirt, Edward Louis, In charge of Electric Welding, Bethlehem Shipbuilding Corp. Ltd., 111 Broadway, New York, N. Y.

***Kalin, Albert**, Chief Electrical Gunner, Radio Laboratory, Navy Yard, Puget Sound; res., 1146 Franklin Ave., Seattle, Wash.

Killgore, Lloyd M., Electrical Engineer, General Electric Co.; res., 27 Courtlandt Place, Pittsfield, Mass.

Kuhn, Louis, Sub-Inspector, Machinery Division, Navy Yard; res., 269 Martense St., Brooklyn, N. Y.

Larson, Iner John, Telephone Engigineer, Western Electric Co., 463 West St., New York, N. Y.

Lautrup, George William, Electrical Engineer, Otis Elevator Co., 26th St. & 11th Ave., New York; res., 87 N. Broadway, Yonkers, N. Y.

Lewis, Jacob D., Electrical Engineer, Otis Elevator Co., 26th St. & 11th Ave., New York; res., 276 Hawthorne Ave., Yonkers, N. Y.

McCully, Leonard Bowman, Production Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 430 Ross Ave., Wilkinsburg, Pa.

Mitchell, Henry Edward, Sales Engineer, The Hessel & Hoppen Co.; res., 590 Winthrop Ave., New Haven, Conn.

Mitchell, William P., M**anager**,Turnbull & Jones, Ltd., Emerson St.; res., Gladstone Road, Napier, N. Z.

Morton, Robert Bass, Engineer, Air Nitrates Corp., 469 Fifth Ave., New York, N.Y.; res., 29 Fairfield St., Montclair, N. J.

Murphy, Joseph P., Electrican, Bethlehem Shipbuilding Co.; res., 1428 Golden Gate Ave., San Francisco,Cal.

***Nichols, P. H.**, Private, Engineers' Officer's Training School, Ga. School of Tech.; res., 60 Milledge Ave., Atlanta, Ga.

***Olsen, R. B.**, Electrical Draftsman & Engineer, Bethlehem Loading Co., Mays Landing; res., 19 So. 2nd St., Pleasantville, N. J.

Peck, Charles Northrop, Sales Dept. Correspondent, Wagner Electric Mfg. Co.; res., 5660 Kingsbury Blvd., St., Louis, Mo.

Perrine, Edward Scott, Girard, Illinois.

Pillai, N. Krishna, Assistant Electrical Engineer, Assam Oil Co., Ltd., Digboi, Assam, India.

Priester, Ernest William, Factory Inspector, National Workmen's Compensation Service Bureau; res., 3411A Pestalozzi St., St. Louis, Mo.

Sarazin, Robert, Electrical Engineer, Fink & Joras, 21 Rue Edouard-Nieuport, Suresnes, (Seins) France,

Scott, Marland Fall, Engineering Dept., Indiana Public Service Commission; res., 1061 Eugene St., Indianapolis, Ind.

See, Elliot McKay, Erecting Engineer, Constructing Dept., General Electric Co., Schenectady, N. Y.

Shackleton, S. P., Telephone Engineer American Telephone & Telegraph Co., 195 Broadway, New York, N. Y.

Sherriff, William Milton, Operator in charge Substation, Hydro-Electric Power Commission; res., 362 Ottaway Ave., London, Ont., Canada.

Stiles, Ernest Lee, Electrician, Panama Canal, Ancon, Canal Zone.

Trott, Wallace W., Electric Meter Inspector, Hydro-Electric Power Commission of Ontario; res., 49 Spadina Ave., Hamilton, Ont., Canada.

Viessman, Warren, Ensign, U. S. N. R. F.; res. 198 Crystal Ave., New London, Conn.

Williams, Eldred Wheelock, Meter Dept., Montana Power Co.; res., 709 W. Galena St., Butte, Mont.

Wolcott, Edwin Miller, Manufactures Agent, Electrical Insulating Materials, 1042 Granite Bldg. Rochester, N. Y.

***Wylie, Robert,** Factory Engineer, Ft. Wayne Works, General Electric Co.; res., 2107 Broadway, Ft. Wayne, Ind.

Yuen, Keyih S., Student, Pratt Institute; res., 231 Ryerson St., Brooklyn, N. Y.

*Former enrolled students.
Total 54.

ASSOCIATES REELECTED DECEMBER 13, 1918

Cohen, Louis, Consulting Engineer, Signal Corps, U. S. A., Prof. Radio Engg., George Washington University, Washington, D. C.

Fahy, Frank P., Consulting Magnetic Engineer, 50 Church St., New York; res., 31 Sidney St., New Rochelle, N. Y.

Simon, Emil J., Radio Engineer, 217 Broadway, New York, N. Y.

MEMBERS ELECTED DECEMBER 13, 1918

Caldwell, James, Captain, Consulting Engineer & Electrician, 190 W. George St., Glasgow; res., Carlton, Symington, Lanarkshire, Scotland.

Douglas, Charles H., Distribution Engineer, Union Electric Light & Power Co., 315 N. 12th St., St. Louis, Mo.

Flight, William Stanley, Technical Electrical Engineer, British Westinghouse E. & M. Co.; res., 21 Primrose Ave., Urmston, Manchester, Eng.

Lyons, Benjamin Franklin, Vice-Pres. & Gen. Mgr., Beloit Water, Gas & Electric Co., 429 E. Grand Ave., Beloit, Wis.

Montabone, A. J. F., Consulting Engigineer, Imperial Theatre Bldg.; res., 25 De L'Epee Ave., Montreal,Quebec.

Smith, J. Fred, Asst. Electrical Engineer, Air Nitrates Corp., 469 5th Ave., New York, N. Y.; res., 164 Ashland Ave., Bloomfield, N. J.

FELLOW ELECTED DECEMBER 13, 1918

Varley, Thomas Wilcock, Consulting Engineer, The Auto Coil Co., Jersey City N. J.; res., 423 W. 120th St., New York, N. Y.

TRANSFERRED TO GRADE OF FELLOW DECEMBER 13, 1918

Bryans, Henry B., Engineer, Counties Gas and Electric Co., Norristown, Pa.

Gaby, Frederick A., Chief Engineer, Hydro-Electric Power Commission of Ontario, Toronto, Ont.

TRANSFERRED TO GRADE OF MEMBER DECEMBER 13, 1918

Brofos, Einar A., Telephone Engineer, Western Electric Co. Ltd., London, England.

Brown, Bedford J., Superintendent of Meter Dept., Southern Power Co., Charlotte, N. C.

Combs, Robert H., General Manager and Chief Engineer, Prest-O-Lite Co. of Canada, Ltd., Toronto, Ont.

Elsom C. H., Member of Firm, West Virginia Engineering Co., Charleston, W. Va.

Grant, Louis T., Major E. R. C., Office of Chief of Engineers, Washington, D. C.

Lopez, Ernesto F., Manager, J. K. Robinson, Inc., New York, and Suc. J. K. Robinson, Iquique, Chile, S.A.

Pennington, Paul, Lieut., (J. G.) U.S. N. R. F., Radio Officer, U. S. S. Orizaba.

Proctor, Elwynne B., Chief Insurance Engineer, Marine Underwriters, New York, N. Y.

Sclater, Robertson H., Inspector, Southern Underwriters Ass'n, Richmond, Va.

Sirnit, John A., Designing and Electrical Engineer, Alabama Power Co., Birmingham, Ala.

Stafford, R. T., Manager, Allis-Chalmers Mfg. Co., Seattle, Wash.

Terrell, Charles F., Superintendent of Transformation, Puget Sound Traction, Light & Power Co., Seattle, Wash.

Willey, Frank W., Member of Firm, Willey-Wray Electric Co., Cincinnati, O.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its regular monthly meeting, held on December 30, 1918, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

Magalhaes, Frank V., Superintendent of Test Dept., N. Y. Edison Co., New York, N. Y.

Wyman, Walter Scott, Treasurer & General Manager, Central Maine Power Co.; General Manager, Adirondack Electric Power Corp.; Augusta, Me.

To Grade of Member

Berger, Julius G., Chief Engineer, Wm. Gordon Corp., Philadelphia, Pa.

Calman, Cecil G., Engineer, Wm. Adams, & Co. Ltd., Sydney, Australia.

Clark, H. O., Jr., Captain, Quartermaster Corps, Construction Div., Camp Logan, Tex.

Harden, William H., Engineering Dept., American Telephone & Telegraph Co., New York, N. Y.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before January 31, 1919.

Abbott, G., New York, N. Y.
Abrahams, A. A., Philadelphia, Pa.
Adams, R. E., Boston, Mass.
Addy, J. G., Jr., Brooklyn, N. Y.
Allwein, A. F., Schenectady, N. Y.
Ambrose, G., Akron, O.
Anderson, J. E., Joliet, Ill.
Anderson, S. H., New York, N. Y.
Arany, L., New York, N. Y.
Arlin, H. W., E. Pittsburgh, Pa.
Aznar, L. F., Schenectady, N. Y.
Babbitt, A. K., Hampton Roads, Va.
Bagnall, F. W., Detroit, Mich.
Barney, E. J., Dayton, O.
Baxter, C. W., Washington, D. C.
Betts, A. J., Columbus, O.
Blumberg, L., Camp Dix, N. J.
Bowman, G. M., Kansas City, Mo.
Bradley, W. T., Newark, N. J.
Brentlinger, C. McA., New York, N. Y.
Brock, G., Chicago, Ill.
Brooks, H. G., Philadelphia, Pa.
Brown, G. W., Detroit, Mich.
Brussell, C. J., Brooklyn, N. Y.
Burger, E. E., Erie, Pa.
Butler, T. W., New London, Conn.
Chadwick, G. L., Portland, Me.
Chase, F. O., Pittsfield, Mass.
Clark, L. I., New York, N. Y.
Clarke, W. H., Toronto, Ont.
Clay, N. S., E. Pittsburgh, Pa.
Cohen, S., New York, N. Y.
Consler, W. J., Rochester, N. Y.
Cooper, C. B., New York, N. Y.
Cordell, P. M., McAlester, Okla.

Cordes, H. A., Los Angeles, Cal.
Crews, C. R., (Member), Kingsport, Tenn.
Daunais, E. H., Waterbury, Conn.
Deale, R. C., Babylon, L. I.
Demorest, I. R., Detroit, Mich.
Dexter, M. B., Springfield, Mass.
Di Cesare, G. E. N., Brooklyn, N. Y.
Dickey, D. A., E. Pittsburgh, Pa.
Donnell, P. S., Little Silver, N. J.
Dow, W., Princeton, N. J.
Drake, C. H., Chicago, Ill.
Dubilier, W., New York, N. Y.
Duff, C. K., Toronto, Ont.
Eckley, W., Schenectady, N. Y.
Ellefson, S., Schenectady, N. Y.
Faris, D. D., E. Pittsburgh, Pa.
Ferrey, F. G., Greenfield, Mass.
Finley, J. C., Watertown, N. Y.
Fitchen, J. H., Brooklyn, N. Y.
Flansburg, P. L., Haskell, N. J.
Foley, J. H., E. Pittsburgh, Pa.
Fox, L. R., Easton, Pa.
Freed, J. D., New York, N. Y.
Ford, F. R., Philadelphia, Pa.
Frick, C. W., Schenectady, N. Y.
Gallaher, H. T., Moline, Ill.
Gannett, H. E., Chicago, Ill.
George, C. H., Tacoma, Wash.
Goldhammer, M. H., Chicago, Ill.
Graham, F. O., Detroit, Mich.
Grugel, H. W., Chicago, Ill.
Haig, A. L., Philadelphia, Pa.
Hall, H. W., W. Lynn, Mass.
Hall, J. D., Washington, D. C.
Hamer, F. C., Chicago, Ill.
Haselton, M. L., Fort Totten, N. Y.
Hasler, J. F., Sheffield, Ala.
Hodgson, J. A., Montreal, P. Q.
Hoerath, J. J., Schenectady, N. Y.
Hood, C., Chicago, Ill.
Horing, H. H., Milwaukee, Wis.
Howard, J. G., Pittsburgh, Pa.
Hughes, G. A., (Member), Youngstown, O.
Hughes, R. J., Minneapolis, Minn.
Huntington, M. B., Rochester, N. Y.
Johnson, A. W., Chicago, Ill.
Johnson, E. T., E. Pittsburgh, Pa.
Junken, L. H., Pittsboro, Ind.
Keller, F. R., New York, N. Y.
Kellogg, C. W., Keokuk,.Ia.
Kelly, J. B., Ft. Collins, Colo.
Kennedy, J. B., Portland, Ore.
Keyes, A. H., (Member), Lawton, Okla.
King, F. C., Rochester, N. Y.
Kirk, W. B., Schenectady, N. Y.
Kneale, R. M., Cleveland, O.
Kniskern, F. B., E. Pittsburgh, Pa.
Koch, J. R., Johnstown, Pa.
Koelbel, F. D., Detroit, Mich.
Kramer, R. S., Philadelphia, Pa.
Krotzer, J. E., Humphreys, Va.
Kusner, L., Philadelphia, Pa.
Landers, F. C., Lockport, N. Y.
Landman, S. J., Keokuk, Ia.
Lang, E. C., Chicago, Ill.
Larson, D. C., New York, N. Y.
Laurer, G. A., Jr., Brooklyn, N. Y.
Leech, V. E., Los Angeles, Cal.
Leeds, J. L., Gloucester, N. J.
Lind, J. D., Wilkinsburg, Pa.
Lindeman, J., New York, N. Y.
Litton, D. S., Muscle Shoals, Ala.
Loomis, E. W., New York, N. Y.
Lu, C. C., Warren, O.
Lusk, W. W., Washington, D. C.
Mansfield, R. G., Niagara Falls, N. Y.
Mason, K. C., Brockton, Mass.
Maxstadt, F. W., New York, N. Y.
McCabe, G. C., Washington, D. C.
McCanne, W. R., Rochester, N. Y.
McGown, D. B., San Francisco, Cal.
McPhail, F. A., Hobart, Tasmania.
Meeker, A. M., Newark, N. J.
Melby, E. C., New York, N. Y.
Mell, F., New York, N. Y.
Mellen, E. R., Newark, N. J.
Menke, O. H., Troy, Ohio.
Merrill, J. L., Columbus, O.
Meyer, D., New York, N. Y.
Meyer, G. C., Kansas City, Mo.
Meyer, H. P., Schenectady, N. Y.
Mickey, B. D., Schenectady, N. Y.
Miller, C. E., Chicago, Ill.
Miller, H. P., Jr., Washington, D. C.
Mills, R. H., New York, N. Y.
Mishler, E. W., Camden, N. J.
Monroe, W. P., Washington, D. C.
Montiller, C. F., Emporium, Pa.
Morton, A. B., Rome, N. Y.
Moyer, H. R., Pittsburgh, Pa.
Murphy, A. J., New York, N. Y.
O'Daniel, C., Cleveland, O.
Oswald, A. A., New York, N. Y.

Otaka, T., New York, N. Y.
Parker, H. L., Conneaut, Ohio
Perry, G. D., North Troy, N. Y.
Peterson, E. G., Milwaukee, Wis.
Phelan, G. S., W. Harwich, Mass.
Pierson, R. T., Rochester, N. Y.
Platt, F., W. Lynn, Mass.
Poole, F. L. Schenectady, N. Y.
Pope, F. R., Pittsburgh, Pa.
Popkin, M. E., New York, N. Y.
Price, G. F., New York, N. Y.
Prochazka, R. V., Chicago, Ill.
Putman, O. E., New York, N. Y.
Putnam, R. E. A., New York, N. Y.
Ray, A. W., Cleveland, O.
Reese, C. E., Springfield, Ill.
Renfro, C. H., Washington, D. C.
Reynolds, H. V., Fresno, Cal.
Reynolds, J. P., McKeesport, Pa.
Rhoads, C. S., Jr., New York, N. Y.
Richardson, C. N., Washington, D. C.
Rudd, F. J., (Member), W. Lynn, Mass.
Russell, C. H., E. Pittsburgh, Pa.
Sakuma, F., Terminal, Cal.
Sarvas, O., New York, N. Y.
Schlick, F. L., Montour Falls, N. Y.
Schmitt, R. F., Cleveland, O.
Servos, F. M., Vancouver, B. C.
Shaw, A. L., Newark, N. J.
Sherwin, A. J., New York, N. Y.
Siefert, P. H., Milwaukee, Wis.
Skinner, D. R., Chicago, Ill.
Skinner, S. I., Kansas City, Mo.
Skone, R. C., Seattle, Wash.
Skutecki, J. W., Akron, Ohio.
Smith, W. R., Calgary, Alta., Can.
Snavely, H. J., Salt Lake City, Utah.
Snedeker, C. F., New York, N. Y.
Sprado, H. R., Washington, D. C.
Steinmayer, A. G., Saltville, Va.
Steven, H. M., Pittsfield, Mass.
Stevens, H. R., Seattle, Wash.
Stevens, S. S., Salt Lake City, Utah
Stone, H. E., Pittsburgh, Pa.
Stoos, F. A., Cincinnati, O.
Sudgen, H., Bethlehem, Pa.
Sutherland, H. T., Jr., Woodhaven, L. I.
Sweet, L. W., Dayton, Ohio.
Sykes, C. B., Schenectady, N. Y.
Thomas, B., Jr., New York, N. Y.
Thomas, H., New Castle, Del.
Thomas, H. W., Washington, D. C.
Tigges, A. J., Erie, Pa.
Tompkins, E. R., Roanoke, Va.
Trevor, K. R., Ithaca, N. Y.
Vittie, F. M., Rochester, N. Y.
Wagner, A. J., Rochester, N. Y.
Wang, K. L., Columbia, O.
Wantz, J. B., Chicago, Ill.
Warner, R. G., New Haven, Conn.
Waters, F. E., Philadelphia, Pa.
Wayman, E. E., Washington, D. C.
Weppler, H. S., Toronto, Ont.
White, W. R., Philadelphia, Pa.
Whitney, C. A., New York, N. Y.
Williams, R. C., Philadelphia, Pa.
Williams, W. A., Lynn, Mass.
Williamson, C. A., Youngstown, O.
Winterer, H. K., Chicago, Ill.
Wood, W. C., E. Pittsburgh, Pa.
Wronker, R., Chicago, Ill.
Youtz, J. P., Schenectady, N. Y.
Total 209

Foreign Applications

Barrozo, R. F., Rio de Janeiro, Brazil.
Just, J. S., (Member), Brisbane, Queensland.
Kahai, H. S., Sind, India.
Karuven, M., Malabar, S. India.
Mok, K. Y., Hankow, China.
Shiraishi, M., Tokyo, Japan.
Thielers, N. G., Vasteras, Sweden.
Total 7

STUDENTS ENROLLED DECEMBER 13, 1918

9756 Reyes, A. N., Univ. of Penn.
9757 Rutherford, R. C., Univ. of N. Carolina
9758 Stern, A. W., Cooper Union
9759 Maxwell, J. P., Delaware Coll.
9760 Niland, J. E., The Rice Institute
Total 5

ADDRESSES WANTED

Any reader knowing the present address of any of the following members is requested to communicate with the Secretary at 33 West 39th Street.

Eduardode A. Braga
(former address)
2-4 Stone St.,
New York, N. Y.

Howard K. Cook,
(former address)
Counties Gas & Elec. Co.
Norristown, Pa.
F. C. Dieterich
(former address)
17 Watertown Ave.,
Waterbury, Conn.
H. S. Logan
(former address)
214 15th Ave.
Seattle, Wash.
Merwin, F. R.
(former address)
1831 T St.,
Sacramento, Cal.
Lincoln Nissley
(former address)
(Room 1213, Pioneer Bldg.,
St. Paul, Minn.
Louis F. Nosek
(former address)
2245 E. 82nd St.
Cleveland, Ohio.

PERSONAL

Meldon H. Merrill and Thomas B. Sweeney announce the organization of the firm of Merrill, Sweeney & Co., engineers, managers and purchasing agents for public service properties, with offices at 50 State Street, Boston, Mass.

Dwight P. Robinson & Co., Inc., Constructing and Consulting Engineers, announce the opening of their offices at 61 Broadway, New York. This organization is prepared to construct, either from their own designs or from designs of others, hydroelectric developments, steam power plants, transmission systems, industrial plants, housing developments and steel and reinforced concrete structures; to undertake the electrification of steam railways and to make engineering and financial reports and appraisals.

Vratislav Adolph Zehr, consulting engineer of the E. T. Perkins Engineering Co. of Chicago, formerly in charge of the Green Bay Levee & Drainage District construction is now superintendent of construction at the Rocky Ford Drainage District, Pekin, Ill.

Captain George B. Nichols has obtained his discharge from the Engineer Corps of the U. S. Army and has returned to his former position of Chief Engineer in the Dept of Architecture, Albany, N. Y.

Herbert B. Reynolds, formerly a fuel engineer in the United States Bureau of Mines, has returned to the Motive Power Department of the Interborough Rapid Transit Company of New York City as Mechanical Research Engineer.

OBITUARY

Henry E. Randall, Jr., died from influenza on October 21 at Montreal, Canada. Mr. Randall graduated from M. I. T. in 1913 and then entered the employ of the Shawinigan Water and Power Co., first at Cedar Rapids and later at the companys' office in Montreal. He finally became power sales engineer and in October 1 severed his connection with the company to become general manager of the Ludlum Electric Furnace Corporation, the position he held at the time of his death. Mr. Randall was elected an Associate in the Institute in 1917.

Lieut. Colonel Frank J. Duffy, of the 103rd Engineers, U. S. Army was killed in France on August 17, 1918. Colonel Duffy was formerly General Foreman, Electric Dept., D. L. & W. R. R. at Scranton, Pa. He became an Associate in the Institute in 1911 and was transferred to the **Grade of Member** in 1917.

Archer F. Moray formerly, Chief Operating Engineer of the St. Maurice Paper Co., Ltd., Montreal, P. Q., died from the effects of influenza on October 11, 1918. Mr. Moray was elected an Associate in the Institute in 1911.

EMPLOYMENT SERVICE

ESTABLISHMENT OF ENGINEERING SOCIETIES EMPLOYMENT BUREAU

The employment service which has been maintained for many years by the Institute has satisfactorily met the demands upon it and has been greatly appreciated by the membership at large, many of whom have obtained desirable engagements through it. The individuals and industries seeking competent engineers have also been greatly benefited.

Similar effective service has been maintained by some of the other national engineering societies, and for sometime the desirability of more closely coordinating the employment activities of these societies and broadening the scope of the service has been discussed, as a result of which the establishment of the Engineering Societies Employment Bureau under the direction of a Board of Management consisting of the Secretaries of the American Society of Civil Engineers, the American Institute of Mining Engineers, the American Society of Mechanical Engineers and the American Institute of Electrical Engineers, was authorized at a meeting held November 21 by the Engineering Council, which is the instrument created by the four societies named above for the purpose of conducting activities of common interest.

In creating this joint bureau the Engineering Council turned over to the Board of Management the office equipment, records and operating staff of the American Engineering Service, a similar body organized by Engineering Council and representing several engineering societies including the Institute, which had been engaged during the war in assisting the various branches of the Army, Navy and other governmental departments to obtain suitable engineering personnel.

The Bureau is especially needed in the period of readjustment upon which the country is just entering. One of its most important functions will be to aid engineers who have been in military service to find suitable engagements upon their return to civilian life.

The Bureau will not be conducted exclusively for the benefit of members of the societies named above; non-members who are properly introduced will also be registered. No charge will be made either to the available engineer or the organization or individual seeking engineering talent.

The number of opportunities for employment of which the Institute and the joint bureau have knowledge does not at present equal the number of engineers whose services are available, and as this disparity will be accelerated as demobilization of military forces progresses, the cooperation of members of the Institute, industrial establishments and others needing the services of engineers is earnestly desired. The necessary qualifications for each position and the approximate salary should be stated in each case.

The Board of Directors of the Institute has instructed the Secretary to continue the Institute employment service substantially as rendered to the membership for many years past and has authorized him to coordinate this service with similar activities of other engineering societies.

The plan for coordination will not involve any limitation of the privilege previously given to Institute members to have, upon application to the Secretary, brief announcements of their qualifications published under key numbers in the Institute PROCEEDINGS, but on the contrary, will result in the members' names being carried also on the joint bureau's lists. Announcements of vacancies will also be published as formerly but in many instances vacancies will not be announced in this manner, as they will frequently be filled promptly from the list of available men on the files of the Institute and the joint Bureau.

Communications may be sent either to the headquarters of the Institute, or to Mr. W. V. Brown, Manager Engineering Societies Employment Bureau, 29 West 39th Street, New York.

ENGINEERING SERVICE BULLETIN

Opportunities.—The Institute is glad to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in the BULLETIN. The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Services Available.—Under this heading brief announcements (not more than fifty words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office reference files.

Note.—Copy for publication in the BULLETIN should reach the Secretary's office not later than the 20th of the month if publication in the following issue is desired. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

OPPORTUNITIES FOR SERVICE

V-447. Steam-electrical engineer for 1200 H-P plant in New Jersey. Man not afraid, if necessary, to put on overalls. Experience in electro-chemical factory operation valuable. Supervision of two operating engineers. Salary dependent on capability.

V-448. Graduate physics or science, post graduate or Ph. D. preferred, for special physical and electrical research in small well equipped laboratory. Previous experience not essential. Permanent position.

V-449. Draftsmen and detailers wanted for industrial plant layout work, preferably men with experience in elevating and conveying machinery. State age, education, nationality, previous experience and salary desired.

V-450. A well established company manufacturing both alternating and direct current motors and generators has a splendid opening for a designing engineer. None but A-1 experienced engineers considered. State age and experience on both alternating and direct current design.

V-451. Large electrical manufacturer needs man familiar with switchboards, circuit breakers, and meters, who knows how to write. Technical graduate preferred.

V-452. Superintendent of electrical distribution for town of 30,000. Executive ability necessary, also experience in high tension transmission distribution and meter departments. Salary $1800. to $2400.

V-453. Meter expert. Large operating company in the east desires services of man capable of calibrating and maintaining A. C. and D. C. meters, relays, and similar electrical apparatus. State experience and salary desired.

V-454. Young engineer, several years experience operating, drafting or testing, for boiler room, generating station and switchboard layout. Opportunity for young man willing to work. Salary dependent on ability and experience.

V-455. Wanted—Man having technical training for general steam and electrical testing work in New York City. Salary approximately $2000. per year. State age, education and experience.

V-456. Electrical engineer with theoretical knowledge of physics and chemistry wanted by eastern manufacturer of fuses. Give age, experience and minimum salary.

V-457. Cost engineer to oversee cost keeping and raw material distribution wanted by eastern manufacturer of fuses.

V-458. Experienced salesman with electrical repair company. Four or five years' experience in general electrical machine repairs. Some experience in motor design desirable. Salary $125. per month.

V-459. Man to act as assistant to head of electrical engineering school. Technical knowledge as well as practical experience. Salary to start about $1500 per year.

V-460. Wanted man thoroughly experienced in design of alternating current generators. In reply give age, experience record and salary desired.

V-461. Operator for switchboard in a water-power generating plant. Young man with some electrical training necessary and at a salary of about $100. per month.

V-462. Wanted—Electrical superintendent for hydroelectric power company. Salary about $150. per month.

V-463. Opening for an electrical construction man with hydroelectric power company, general installation and construction work. Salary about $150. per month.

V-464. Manufacturer of electric control apparatus wants young electrical engineer, at least two years practical experience, to do technical writing. Must be familiar with electric motor and control line. Give age, experience and minimum salary.

V-465. Large manufacturer requires a sales manager, thoroughly familiar with design and use of trucks, tractors, storage batteries and accessories. Salary $2000. to $3000., depending on experience.

V-466. Recent electrical engineering graduate, for development and research work with prominent communication company. Must have initiative and ability. Good opportunity, permanent position. Location New York.

V-467. Assistant engineer with technical training and experience in construction and repairs of industrial plants qualified to design special machinery and make layouts of new equipment. Permanent position. Prefer man with experience in chemical plant or office of consulting engineer. State qualifications and details of experience. Salary $1500. to $2000. Location southern Ohio.

SERVICES AVAILABLE

1083. Captain of Engineers, U. S. Army, available about February 1. College graduate, married, ten years' experience in mechanical and electrical engineering and manufacturing of which last four and a half have been executive work. Minimum salary $3,000.

1084. Electrical and mechanical engineer, age 33, desires technical executive position, ten years varied experience switchboards, substations, machine shops, marine appliances, development work. College graduate.

1085. Power Specialist. Ten years' experience design, construction, operation electric power plants, high tension distribution substations and industrial use of electric power. Had recent charge of electrical and mechanical design (fifty men), supervision of construction (one thousand men) large steel shipyard. Executive engineer, age 30, married, available January 1, 1919.

1086. Power Sales Engineer. Graduate engineer wishes to engage in power sales work with large operating company upon his release from naval service. Experience of several years covers work done with large power and operating companies. Annual revenue from sales and contracts has averaged better than $75,000. Excellent references as to character, fitness and ability can be given. Available February 1, 1919. Salary $175.

1087. Electrical-Mechanical Draftsman. Graduate Rose Polytechnic Institute 1915. In charge drafting last three years on work including shell machinery, oil well equipment, hydraulic pumps, safety work. Student Alexander Hamilton Institute, Member A. I. E. E. Would like opportunity leading to works management, efficiency or sales engineer.

1088. Electrical-Mechanical Engineer. Age 30. Technical graduate with specialized experience on installation and maintenance of A. C. and D. C. motors, automatic control, substations and wiring. Competent to handle men and take complete charge of electrical department of industrial plant. References to present employer. Give full details. Available within month.

1089. Electrical engineer, college graduate, with six years practical and executive experience in the design and manufacture of electrical apparatus desires position as assistant to manager or assistant to chief engineer of company manufacturing electrical apparatus. At present hold commission in Ordnance Department U. S. A. Age thirty. Minimum salary $2500.

1090. Graduate electrical engineer with ten years' experience in construction and maintenance of telephone plant, wishes responsible position as telephone plant superintendent or engineer, or as manager for good sized telephone company. Now in the military service.

1091. Executive engineer, technical graduate, eight years' experience with large electrical manufacturer and five years as superintending engineer with street railway, desires position with power or railway utility or with consulting and contracting company. Age 39. Married. Good references.

1092. Electrical technical graduate, 29 years, married, Associate A. I. E. E. Yale Engineering Assoc. Two years linework and meter testing central station. Eight months G. E. Student course, two years sales department. Eight months electrician and three years superintendent hydroelectric plant. Available January. Want position as power salesman, efficiency engineer, or division superintendent in East or Middle West.

1093. Engineer and Executive. Technical graduate with ten years varied mechanical and electrical experience along engineering and administrative lines. Principal experience on construction, management and consulting engineering for gas, electric and street railway properties. Available February 1 for responsible position in public utility or industrial company. Salary $5000.

1094. A Captain of Signal Corps, now in the East, electrical engineer, age 30, married, Associate A. I. E. E., with six years' experience in power and substation construction, operation and maintenance, handling all kinds of electrical apparatus, including telephone systems, expects to secure discharge soon. Executive ability and experience in handling men.

1095. Research engineer completing military duties at Government laboratory is available for industrial experimental department about to be or already established. Broad scientific, chemical, mechanical experience. Successful patentee.

1096. Electrical-Mechanical Engineer. Graduate E.E., Member A. I. E. E., now employed, age 37, married, desires permanent location. Executive work near New York City preferred. Recently designed and constructed large shell loading plant and housing proposition. Have designed, constructed and operated electric railway, light and power and high tension stations and high tension transmission lines. Will consider appraisal work. Available soon.

1097. Electrical engineer wishes to locate with firm in New York City on construction work. Graduate of G. E. Student course. Present position with large loading company in South Jersey on power plant equipment, power and lighting design and supervisor on construction. In reply please arrange for interview. Available January 15.

1098. Technical graduate, age 31, married, executive as well as engineering ability, ten years varied electrical and mechanical experience wishes to connect with industrial or power business as superintendent of power or other responsible position. Available in one month. Present salary $2000.

1099. Steel mill electrical engineer and department manager just returning from foreign service as First Lieutenant of Engineers will soon be available for a design, sales or administration engineering position. Two college degrees in engineering. Eight years' experience in the above lines. Age 31, and in best of health.

1100. Electrical engineer, 36, married, eighteen years varied mechanical and electrical experience covering steam plants, electrical shop and test, drafting, industrial engineering, teaching high and low tension design work, general engineering work. Available on reasonable notice. Minimum salary $4000. Position with considerable travel preferred.

1101. Manufacturing executive. Mechanical engineer. Fifteen years' experience in factory management. Two years general manager, two years works manager, and two years production manager in automobile factory. Five years industrial engineer for large plants in the East. Thoroughly familiar with all phases of manufacturing in big production, engineering, purchasing, stock and production, shipping, costs and sales.

1102. A graduate of a well-known technical university in electrical engineering, also a large portion of civil engineering course, desires a permanent connection with a firm offering good chances for an ambitious man. Age 25. Experience: assistant construction engineer, General Electric heavy machine testing. Foreign position considered. Good references.

1103. Graduate electrical engineer, age 32, eight years' experience in maintenance, testing and inspection of electric car lighting equipment desires position as sales engineer or executive in maintenance work. Salary $2400.

1104. Experimental electrical engineer, recently released from war service. Six years varied experience with well-known electrical manufacturing companies. Salary $200. per month.

1105. Electrical engineer, 30 years of age, married, technical education with twelve years' experience on power plant and substation design and construction. Competent to handle position as electrical engineer for a light and power company. Also experienced in steel mill electrical requirements. Available February 1, 1919. Minimum salary $2700.

1106. Electrical-Mechanical Engineer, technical graduate, fifteen years' experience. Associate member A. I. E. E. Specialist on motor drives and industrial power systems. Desires position as chief electrician of large industrial concern or as industrial power expert with central station company. Now employed, but desire wider opportunity for service.

1107. Electrical engineer, executive as well as engineering ability. Familiar with operating rules that are productive of the best results. Would prefer position with supervision over power station transmission, distribution and meter departments in town of ten to twenty thousand inhabitants. Available on thirty days' notice.

1108. Graduate electrical engineer, age 26, experienced in construction and maintenance electrical and mechanical. At present commissioned in Naval Reserve. Will be open for engagement about February 1, 1919.

1109. Instructor in electrical engineering. Graduate degree from University in Middle West. Three and one-half years experience in teaching. Resigned former position to teach radio telegraphy in military school during the war. Two years practical experience G. E. test, and power plant engineering. Salary $1500. Age 29.

1110. Captain, Engineers, U. S. Army, expects to be released from service in January. Technical graduate in electrical engineering. Actively engaged in engineering work for past eleven years. Experienced in design, construction and operation of both steam and hydroelectric properties, mostly with large companies. Have been superintendent and manager during last four years. Seeks opportunity to use experience and ability to mutual advantage.

1111. Electrical-mechanical engineer draftsman, university graduate, sixteen years' experience in design, proposal and construction of switchboards, power stations, industrial plant electrification (light and power), transmission and distribution in Europe, United States and Cuba. Working knowledge of French and Spanish. Excellent references.

1112. Naval Reserve Senior Lieutenant, age 28, with demonstrated inventive ability, desires responsible engineering position with electrical manufacturer. Electrical engineering degree, seven years broad and exceptional experience with General Electric Company, especially in development of signalling, protective and circuit-controlling devices. Commissioned in the Navy. Now member of Annapolis faculty. P. O. Box 515, Annapolis, Maryland.

1113. Army Officer who will be discharged about February 8th desires a position. Electrical engineering graduate with three years practical engineering experience. Age 28.

1114. Electrical engineering graduate, age 26, married, with four years' experience in the design, construction and operation of generating stations, substations and high tension transmission lines, desires position as district engineer with power company or similar position.

1115. Electrical engineer, 31, university graduate, seven years' experience in design and construction of power plants, substations, transmission lines, etc. Have had charge of designing. At present assistant engineer with large power and railway company.

1116. Mechanical-electrical engineer graduate Cornell, member A. I. E. E., with seven years' experience as experimental and research engineer. Thoroughly familiar with air-brake and automatic railway signal work. Junior Lieutenant U. S. N. R. F. Have just been ordered inactive duty from U. S. Naval Torpedo Station, Newport, where engaged as assistant experimental officer. Immediately available.

1117. Graduate electrical and mechanical engineer, six years college training, seven years experience construction, design, operation, installation, maintenance and management, desires permanent position as engineer or executive. Have had central station, small plant, transmission line, factory, building and ship experience. Member A. I. E. E. Married, Age 30.

1118. Technical and practical man, experienced in installation and repair work. Have been engaged as an instructor at the U. S. N. Electrical School for the past two years. Desirous of now becoming connected with a progressive concern. Reconstruction work would be preferred. (Age 24).

1119. Executive of public utility with engineering experience, at present connected with Government service as Fuel Administrative Engineer, desires position requiring valuable business experience and executive ability. Minimum salary considered $6000. per annum.

1120. Engineer, mechanical and electrical, graduate University of Penn., experienced in the construction, inspection and operation of power and substations. At present Lieutenant U. S. N. (engineering duties only). Desires a position as sales engineer or executive. Available after January 1, 1919.

1121. Executive engineer, five years' experience maintenance power apparatus, five years' experience design electrical specialties. Experienced in solution, "how to do it electrically". Member A. I. E. E. Has held active commission as electrical engineer in Navy during war. Available April 1. Valuable to consulting engineer in industrial power, or to manufacturer electrical specialties, navy or commercial.

1122. Electrical engineer, technical graduate, seven years' experience in testing electrical equipment and in appraisal and inspection of public utility properties. Age 28; married. Salary $1800.

1123. Technical graduate, four years experience in electrical contracting, as field and office engineer on industrial light and power installations, desires permanent position with general contractor or manufacturer. Have thorough business as well as electrical experience. Age 24.

1124. Graduate electrical engineer with six years' experience steam generating station operation, one year design, one and a half year of war service as captain of engineers in army, desires permanent location in New York City in executive capacity or as electrical engineer. Age 30, married. Salary $3000.

1125. A graduate electrical engineer of twelve years' experience desires a business connection with a small, growing manufacturing firm; or with a small engineering and contracting concern. In reply please give full details.

1126. Commercial or operating engineer central station. Long experience in power station management, steam and electrical engineering. At present Lieutenant Naval Reserve Force. Past year in charge of radio experimental work. Desire definite proposition before effecting release from active duty. Married. Age 32.

1127. Graduate electrical engineer, Associate A.I.E.E., twenty years' experience electric light and power construction, operation and maintenance, power house and overhead and underground distribution. Sixteen years one public utility company as electrical engineer and general superintendent. At present civilian Government service. Minimum salary $3000.

1128. Army officer being discharged. Technical electrical engineer with seven years' experience as engineer, production man, sales engineer and sales manager successively of electrical machinery manufacturer wants position as sales manager of electrical manufacturing concern. Minimum salary $6000. Especially prefers connections with a specialty company that is willing to sell stock to new blood.

ACCESSIONS TO THE ENGINEERING SOCIETIES LIBRARY

(From November 1, 1918, to November 30, 1918)

Unless otherwise specified, books in this list have been presented by the publishers. The Societies do not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

AERO ENGINES, MAGNETOS AND CARBURETORS.

By Harold Pollard. N. Y., The Macmillan Co., 1918. 84 pp., 15 illus., 15 pl., 6 x 4 in., cloth, $1.

A brief manual, written in simple language and intended for beginners, which makes no pretense to be an exhaustive technical treatment of its subject.

AUTOMOTIVE MAGNETO IGNITION:

Its Principle and Application, with special Reference to Aviation Engines. By Mich. E. Toepel. 1st edition. N. Y., Spon and Chamberlain; Lond., E. & F. N. Spon, Ltd., 1918. 103 pp., illus., charts, diags., 8 x 4 in., cloth, $2.

Presents the subject in the form of questions and answers covering the general principles of magneto ignition. References to specific types of apparatus have been avoided. Numerous illustrations and wiring diagrams are included.

CENTRAL STATION HEATING:

By Byron T. Gifford. 2nd edition. N. Y., Heating and Ventilating Magazine Company, 1918. 278 pp., 34 illus., tab., 9 x 6 in., cloth, $3.

Particular attention has been directed in this edition to the regulations adopted by the various state governments for the control of public utilities, especially to the methods of cost accounting necessitated by rate and valuation investigations. The discussion of high-pressure steam distribution has been expanded and the entire book has been revised.

COAL AND ITS SCIENTIFIC USES.

By William A. Bone. (Monographs on Industrial Chemistry) Lond. and N. Y., Longmans, Green and Co., 1918. 15+491 pp., illus., pl., charts, diags., tab., 9 x 6 in., cloth, $7.

The author, who was chairman of the British Association Fuel Economy Committee in 1915–17, has tried to give in essential outline an account of the present state of science and practice in relation to coal and its various uses.

Beginning with an account of the general and scientific aspects of the coal question from a British point of view, there follows a review of the present state of science regarding the origin and chemistry of coal, including its distillation, oxidation and combustion. The latter part of the book considers the principal economic and industrial uses of coal as a fuel, and closes with an account of surface combustion.

The monograph is intended to provide a succinct account of the statistical, chemical and technical aspects of the subject as a whole, without unnecessary detail, for use by the scientific public, and especially by the chemical section of it.

CONVEYANCE AND DISTRIBUTION OF WATER FOR WATER SUPPLY:

Aqueducts, Pipe-lines and Distributing Systems. A Practical Treatise for Water-works Engineers and Superintendents. By Edward Wegmann. N. Y., D. Van Nostrand Co., 1918. 663 pp., 367 illus., 8 pl., 9 x 6 in., cloth, $5. (Gift from author).

By restricting himself to the conveyance and distribution of water, the author has been able, within the limits of a single volume, to discuss the subject in sufficient detail to be of practical value to engineers and superintendents of water works.

Beginning with a chapter on the consumption of water, the flow of water in aqueducts and pipes is next discussed. Then follow chapters on the design and construction of pipes, aqueducts, service reservoirs, stand pipes and tanks, fire protection and high pressure systems. The remaining chapters take up maintenance and operation, the cleaning of aqueducts and mains, thawing frozen pipes, leakage, electrolysis, pipe tools and the detection and prevention of water waste.

DAVISON'S TEXTILE "BLUE BOOK", UNITED STATES AND CANADA:

Cotton, Woolen, Silk, Jute, Flax and Linen Manufacturers; Dyers, Bleachers and Print Works: Commission Merchants; Converters and Brokers; Yarn, Cotton, Waste, Linter Dealers; Mattress Manufacturers; Wool, Rag and Mill Remnant Dealers; Raw, Thrown and Spun Silk Dealers, &c. With a full classified Directory of Cotton and Woolen Mills and a Textile Supply Directory. 31st annual edition July 1918 to July 1919. N. Y., Davison Publishing Co., (copyright 1918) 1471 pp., 7 maps, 9 x 7 in., cloth, $5.

This directory covers the textile manufacturers, dyers, bleachers, printers, commission merchants, dealers, and makers of textile mill supplies in the United States and Canada. The various lists are carefully classified for quick reference. The capitalization, officers, equipment, products and railroad connections of each mill are given. Maps showing the location of the textile mills of the country are included.

ELECTRIC WELDING:

A Comprehensive Treatise on the Practice of the Various Resistance and Arc Welding Processes, Covering Descriptions of the Machines and Apparatus Used and the Applications, both in Manufacturing and Repair Work. By Douglas T. Hamilton and Erik Oberg. 1st edition. N. Y., The Industrial Press, 1918. 294 pp., 217 illus., 2 tab., 9 x 6 in., cloth, $2.50.

A summary of present practice. The authors announce that they have had the assistance of the most prominent American firms engaged in this work, and that they have thus been able to present information on the latest improvements and discoveries.

ENGINEERING DIRECTORY:

Buyers' Reference Section.—1918 Edition. A Comprehensive Directory of Manufacturers of Mill, Steam, Mine, Plumbing, Heating and Lighting Supplies, Machinery and Tools. Chicago, The Crawford Publishing Co., (copyright 1918) 566 pp., 11 x 8 in., cloth.

This volume contains a list of American manufacturers, trade names and brands of industrial and engineering supplies and machinery, arranged under approximately four thousand subject headings, and a directory of manufacturers. An extensive cross index to the classification is provided.

THE J. E. ALDRED LECTURES ON ENGINEERING PRACTICE, 1917–18.

The Johns Hopkins University, Department of Engineering. Baltimore. The Johns Hopkins Press, 1918. 263 pp., illus., 2 folded pl., 1 map, 9 x 6 in., paper. (Gift from The Johns Hopkins University).

CONTENTS: Steam-electric Power Plant Design; The Relation between Civil Engineering and Military Engineering; The Development of Concrete Road Construction; Copper Refining; The Coal Problem; The Growth of Electric Systems; The Operation of a Manufacturing Plant; The Control of Stream Pollution; The Manufacture of Structural Steel.

A presentation of the tangible and obvious features and principles of present engineering practice, intended to instruct the undergraduate students of the University in everyday working methods of design, construction, and operation.

MAP READING AND TOPOGRAPHICAL SKETCHING.

By Edwin R. Stuart. 1st edition. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1918. 11 + 139 pp., 46 illus., 1 map, 8 x 5 in., cloth, $1.

This textbook represents the results of the author's thirteen years of experience in the practice and teaching of topographic surveying and sketching at the United States Military Academy.

PRACTICAL SURVEYING AND FIELD WORK:

Including the mechanical Forms of Office Calculations with Examples completely worked out. By Victor G. Salmon. Lond., Charles Griffin & Co., Ltd.; Phila., J. B. Lippincott Co., 1918. 204 pp., 87 illus., 3 folded diag., 8x5 in,. cloth. (Gift from J. B. Lippincott Co.).

The author has endeavored to supply to students a series of calculations which, in connection with well-known textbooks, will equip the young surveyor for the practice of the profession.

The work consists mainly of solutions to questions set in examinations for qualification as surveyors in the South African colonies. It is not intended as a textbook, and includes only so much theory as is necessary to explain the examples.

THE RESULT OF MUNICIPAL ELECTRIC LIGHTING IN MASSACHUSETTS:

By Edmond Earle Lincoln. (Hart, Schaffner and Marx Prize Essays, No. 27). Bost. and N. Y., Houghton Mifflin Co., 1918. 20 + 484 pp., 14 charts, 1 map, 58 tab., 8x5 in., cloth, $3.

As a contribution to the discussion on the advantages and disadvantages of public ownership, the author has prepared this impartial, comparative study of results in one well-established business in a specific locality where adequate records covering a period of years can be secured. The aim of the book is to suggest and exemplify those methods of approach and investigation which may most profitably be followed in future studies of the problems of municipal and state ownership. It is based on a careful, personal statistical study of the annual returns made by the plants to the Massachusetts Board of Gas and Electric Commissioners and a personal survey of the plants themselves.

SCREW PROPELLERS:

and Estimation of Power for Propulsion of Ships. Also Air-ship Propellers. By Rear Admiral Charles W. Dyson, U. S. N. 2nd edition, rewritten. N. Y., John Wiley and Sons, Inc.; Lond., Chapman and Hall, Ltd., 1918. 325 pp., 62 illus., 32 pl., 18 tab., 2 vols. (text and atlas), cloth, $7.50.

The first edition of this work on propeller design suffered, the author states, from two serious faults; one being the vagueness of the method for determining the thrust deduction factor and the other being the method of applying it in determining the characteristics of the propeller. These have both been eliminated to a great degree in this edition and other improvements have been introduced in the text. The author's ideas on cavitation are now fully presented. A chapter on airplane propeller design has been added.

STRUCTURAL SERVICE BOOK, Volume I:

A revised Reprint from the twelve Issues for 1917 of The Journal of the American Institute of Architects Structural Service Department. D. Knickerbacker Boyd, Editor. Wash., The Journal of the American Institute of Architects, 1918. 16 + 226 pp., including Industrial section, 12 x 9 in., cloth, $3.50.

The first volume of an annual review of structural activities throughout the United States with particular reference to the standards adopted or under consideration by the various societies, associations or other agencies whose work concerns itself in any way with the materials which enter into building construction, the methods and safety of their production, manufacture and erection.

The material is classified and indexed for ready reference. Under each heading are given lists of references to publications giving general information, describing recommended practice, and adopted standards.

THEORY OF STRUCTURES.

By Arthur Morley. New edition. Lond. and N. Y., Longmans, Green and Co., 1918. 11 + 584 pp., 319 illus., 4 pl., tab., 9 x 6 in., cloth, $4.50.

The author sets forth the theory of the simpler structures so far as it relates to strength, stiffness and stability. In order to present the subject completely he has included in the earlier chapters considerable matter dealing with the theory of strains and stresses in single pieces, practically as it appeared in his "Strength of Materials."

The discussion is confined to wooden and metallic structures, reinforced concrete being omitted. Worked-out examples form a feature of the text.

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IN SERVICE

IN recognition of the services rendered by the membership of the Institute during the World War the Institute publishes herewith an Honor Roll containing the names of all members who have been in the uniformed forces of the United States and the Allies. Revised to January 1, 1919.

Summary

U. S. ARMY

Major Generals	**7**
Brig. Generals	**5**
Colonels	**9**
Lieut. Colonels	**20**
Majors	**110**
Captains	**219**
First Lieutenants	**187**
Second Lieutenants	**151**
Sergeants	**35**
Corporals	**13**
Miscellaneous	**228**
Total	**984**

U. S. NAVY

Rear Admirals	**2**
Captains	**1**
Commanders	**5**
Lieut. Commanders	**9**
Lieutenants	**31**
Lieutenants (j. g.)	**85**
Ensigns	**71**
Miscellaneous	**69**
Total	**273**

U. S. MARINE CORPS

Lieutenants	**2**

ALLIED FORCES

British Army	**55**
British Navy	**6**
French Army	**5**
Italian Army	**1**
Japanese Navy	**1**
Total	**68**

Total on Honor Roll **1327**

Honor Roll

Membership of the American Institute of Electrical Engineers in service in the Army and Navy of the United States and the Allies in the World War.

This list is made up from replies received at Institute headquarters in response to requests for information regarding members in service, and it is probably not complete. It is requested that omissions or inaccuracies be brought to the attention of the Secretary.

The names of members who have died in service are indicated by an asterisk.

ABADIE, EUGENE H.
Major, Engineer Corps, U. S. Army.

ABBOTT, LEWIS W.
Major, 401st Telegraph Battalion, Signal Corps, U. S. Army.

ABLETT, CHARLES ANTHONY
Lieutenant, Royal Engineers, British Army.

ACHARD, FRANCIS H.
Captain, 24th Engineers, U. S. Army.

ADAM, E. N.
362nd Infantry, U. S. Army.

ADAMS, CHAS. S.
Ensign, U. S. N. R. F.

AGEE, HOWARD H.
Captain, Engineer Corps, U. S Army.

AIME, FRANK L.
U. S. Army.

ALBRECHT, AUGUST H.
134th Field Artillery, U. S. Army.

ALBRECHT, F. C.
Captain, Ordnance, U. S. Army.

ALDEN, C. R.
Provisional Ensign, U. S. N. R. F.

ALDRICH, LOUIS C.
Radio Operator, U. S. Navy.

ALDWORTH, EDWARD L.
Second Lieutenant, Ordnance, U. S. Army.

ALGER, PHILIP L.
First Lieutenant, Ordnance, U. S. Army.

ALLCUTT, C. T.
Engineer Officers' Training School, U. S. Army.

ALLEN, ARTHUR E.
Lieutenant, Royal Air Force, British Army.

ALLEN, E. W.
Major, 341st Infantry, U. S. Army.

ALTLAND, COMER P.
Sergeant, Radio Operator, Signal Corps, U. S. Army.

AMES, AZEL
Major, Coast Artillery Corps, U. S. Army.

ANDERSON, ARVID R.
324th Field Artillery, U. S. Army.

ANDERSON, EARL G.
Second Lieutenant, 302nd Engineers, U. S. Army.

ANDERSON, PIERSON A.
First Lieutenant, Engineer Corps, U. S. Army.

ANDERSON, STEWART W.
First Lieutenant, 307th Engineers, U. S. Army.

ANDRAE, GEORGE H.
1st Engineers' Replacement Regiment, U. S. Army.

ANNETT, F. A.
First Lieutenant, Ordnance, U. S. Army.

ANTHONISEN, R. P.
30th Engineers, Gas and Flame, U. S. Army.

APPLEGATE, K. P.
Lieutenant, U. S. Navy.

ARNETT, W. W.
Sergeant, 328th Brigade, Tank Corps, U. S. Army.

ARNOLD, BION J.
Lieutenant Colonel, Air Service, U. S. Army.

ARNOLD, C. N.
Lieutenant, Junior Grade, U. S. N. R. F.

ARNOLD, HAROLD D.
Captain, Signal Corps, U. S. Army.

ARNOLD, HARRY S.
Captain, Engineers Corps, U. S. Army.

ARTHUR, JAMES B.
First Lieutenant, Ordnance, U. S. Army.

ASHER, LEON
U. S. Navy.

ASHLEY, EDWARD E.
Captain, Air Service, U. S. Army.

ASHMEAD, EDWARD W.
37th Engineers, U. S. Army.

ASHTON, OLIVER
Ensign, Flying Corps, U. S. Navy.

ASIRE, HORACE W.
First Lieutenant, Chemical Warfare Service, U. S. Army.

ATKINSON, KERR
Second Lieutenant, 303rd Engineers, U. S. Army.

ATKISSON, EARL J.
Colonel, 1st Gas Regiment, Engineer Corps, U. S. Army.

AVERBACH, J. E.
First Lieutenant, 490th Aero Squadron, U. S. Army.

AVERY, F. B.
First Lieutenant, 314th Engineers, U. S. Army.

AYRES, MILAN V.
Major, Statistics Branch, General Staff, U. S. Army.

BABCOCK, A. H.
Major, Engineer Corps, U. S. Army.

BACH, WALLIS K.
Ensign, U. S. N. R. F.

BACON, FRANK R.
Major, Ordnance, U. S. Army.

BADGER, C. K.
Captain, 417th Telegraph Battalion, Signal Corps, U. S. Army.

BAER, C. A.
Captain, 56th Engineers, U. S. Army.

BAILEY, R. S.
Flying Corps, U. S. Navy.

BAKER, LOUIS A.
Lieutenant, junior grade, U. S. N. R. F.

BAKER, PAUL W.
Second Lieutenant, 314th Engineers, U. S. Army.

BALDWIN, BERT L.
Major, Engineer Corps, U. S. Army.

BARKER, CHARLES M.
Radio School, Signal Corps, U. S. Army.

BARKER, HARRY
Captain, Engineer Corps, U. S. Army.

BARNERT, MEYER
First Lieutenant, Engineer Corps, U.S. Army.

BARNS, FREDERICK
Master Engineer, 37th Engineers, U. S. Army.

BARRETT, SAMPSON K.
Lieutenant, U. S. N. R. F.

BARROW, GEORGE M.
2nd Lieutenant, Engineer Corps, U. S. Army.

BARTLETT, C. C.
First Lieutenant, Engineer Corps, U. S. Army.

BARTON, PHILIP P.
Major, Engineer Corps, U. S. Army.

BASS, LELAND B.
Second Lieutenant, Air Service, U S. Army.

BAXTER, HAROLD C.
Engineer Officers' Training School, U. S. Army.

BEALE, S. HAROLD
Sapper, Engineers, Canadian Army.

BEALL, JOHN C.
Captain, Signal Corps, U. S. Army.

BEAMES, C. F.
Major, Ordnance, U. S. Army.

BEAR, S. LEE
Second Lieutenant, Coast Artillery Corps, U. S. Army.

BEARY, D. B.
Lieutenant, U. S. Navy.

BEAVER, GEORGE L.
Second Lieutenant, 303rd Engineers, U. S. Army.

BEAZLEY, ARTHUR TETLEY
Captain, British Army.

BECHLEM, A. W.
Lieutenant, U. S. Army.

BECK, VERNON S.
Second Lieutenant, Air Service, U. S. Army.

BECKMAN, FRED. G.
37th Engineers, U. S. Army.

BEHRENS, EDWARD L.
Captain, Engineer Corps, U. S. Army.

BEHRINGER, CHARLES R.
Engineer, Ordnance, U. S. Army.

BELL, RALPH S.
Lieutenant, Signal Corps, Canadian Army.

BELL, W. I.
Captain, Quartermaster Corps, Construction Division, U. S. Army.

BELT, J. H.
106th Engineers, U. S. Army.

BEMAN, R. H.
First Lieutenant, Signal Corps, U. S. Army.

BENEDICT, E. G.
Captain, 301st Engineers, U. S. Army.

BENNETT, A. C.
First Lieutenant, Engineer Corps, U. S. Army.

BENNETT, JOHN L.
Lieutenant, 371 Aero Squadron, U. S. Army.

BENZ, W. KARL
Artillery School, France, U. S. Army.

BENZING, H. F.
Lieutenant, junior grade, U. S. N. R. F.

BERGSTRESSER, HAROLD F.
Instructor, Radio Officers' School, U. S. Army.

BERKELEY, L. R.
First Lieutenant, 107th Engineers, U. S. Army.

BERNHARD, ALBERT H.
Sub-inspector, U. S. Navy.

BERSSENBRUGGE, B.
310th Engineers, U. S. Army.

BESSESEN, BEN. B.
First Lieutenant, 537th Engineers, U. S. Army.

BESSEY, CARL A.
Lieutenant, 113th Engineers, U. S. Army.

BETTS, CHARLES R.
Engineer Corps, U. S. Army.

BETTS, EUGENE
Major, Quartermaster Corps, Construction Division, U. S. Army.

BETTS, H. H.
Captain, Royal Engineers, British Army.

BETTS, PHILANDER
Lieut. Colonel, Quartermaster Corps, Construction Division, U. S. Army.

BEVERIDGE, WM. B.
First Lieutenant, 319th Field Signal Battalion, U. S. Army.

BIDWELL, M. C.
First Lieutenant, Mobile Ordnance Repair Corps, U. S. Army.

BILLINGS, A. W. K.
Lieut. Commander, U. S. N. R. F.

BILLINGSLEY, F. N.
Lieutenant, 301st Engineers, U. S. Army.

BIRDSALL, WILFRED T.
Coast Artillery Corps, U. S. Army.

BISHOP, ALBERT B.
Second Lieutenant, Air Service, U. S. Army.

***BISHOP, REMSEN**
Air Service, U. S. Army.

BLACK, CHAS. N.
Lieut. Colonel, Ordnance, U. S. Army.

BLACKMORE, CHARLES T.
Medical Corps, U. S. Army.

BLAIR, EDWARD J.
Major, 311th Engineers, U. S. Army.

BLAIR, SHIRAS A.
First Lieutenant, Air Service, U. S. Army.

BLAISDELL, JEROME L.
Sergeant, Ordnance, U. S. Army.

BLAKE, EDWIN T.
Captain, Engineer Corps, U. S. Army.

BLAKEMORE, M. N.
Captain, Engineer Corps, U. S. Army.

BLAKESLEE, D. W.
First Lieutenant, 56th Engineers, U. S. Army.

BLITMAN, CHAS. H.
Second Lieutenant, Air Service, U. S. Army.

BLUMBERG, LEO
Sergeant, Quartermaster Corps, U. S. Army.

BODENMULLER, H. R.
Sergeant, 348th Infantry, U. S. Army.

BOGGS, CLARENCE
First Lieutenant, Engineer Corps, U. S. Army.

BOHNERT, ARTHUR M.
Captain, Engineer Corps, U. S. Army.

BOLLE, HERMAN A.
Chief Radio Operator, U. S. Navy.

BONAMY, LEO J.
Recruiting Station, U. S. Army.

BOND, F. M.
Major, Ordnance, U. S. Army.

BOSSHART HARRY J.
37th Engineers, U. S. Army.

BOWER, GEO. W.
315th Infantry, U. S. Army.

BOWES, LAWRENCE C.
503rd Engineers, U. S. Army.

BOYD, RICHARD L.
Major, 325th Infantry, U. S. Army.

BOYD, VALENTINE
Captain, Engineer Corps, Canadian Army.

BRACKETT, ROSS D.
Ensign, U. S. N. R. F.

BRADLEY, ALONZO B.
Captain, Ordnance, U. S. Army.

BRADLEY, C. R.
Air Service, U. S. Army.

BRADLEY, H. H.
Electrician Gunner, U. S. N. R. F.

BRANSON, EDWARD H.
Second Lieutenant, Ordnance, U. S. Army.

BRANTLY, E. C.
Captain, Engineer Corps, U. S. Army.

BRATE, C. F.
Corporal, 303rd Engineers, U. S. Army.

BREED, GEORGE
Lieutenant, U. S. Navy.

BRESSLER, H. V.
Lieutenant, junior grade, U. S. N. R. F.

BRIGHTBILL, FLOYD G.
Second Lieutenant, Coast Artillery Corps, U. S. Army.

BRILL, OSCAR C.
Captain, Signal Corps, U. S. Army.

BRINKMEIER, A. E. H.
Lieutenant, junior grade, U. S. N. R. F.

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Toledo	June 3, '07	W. A. Hill	Max Neuber, 1257 Fernwood Ave., Toledo, Ohio.
Toronto	Sept. 30, '03	A. H. Hull	Ernest V. Pannell, 60 Front Street, West, Toronto, Ont.
Utah	Mar. 9, '17	A. S. Peters	H. T. Plumb, Newhouse Bldg., Salt Lake City, Utah.
Urbana	Nov. 25, '02	A. R. Knight	E. H. Waldo, Univ of Illinois, Urbana,Ill,
Vancouver	Aug. 22, '11	R. F. Hayward	T. H. Crosby, Canadian Westinghouse Co. Vancouver, B. C
Washington, D. C.	Apr. 9, '03	J. E. Smith	Milton Flanders, Bliss Elec. School, Tacoma Park, Washington, D. C.

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Armour Institute	Feb. 26, '04		
Brooklyn Poly. Inst.	Jan. 14, '16		
Bucknell University	May 17, '10		
California, Univ. of	Feb. 9, '12		
Carnegie Inst. of Tech.	May 18, '15		**B. C. Dennison, Carnegie School of Technology, Pittsburgh, Pa.**
***Cincinnati, Univ. of**	Apr. 10, '08		
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*Highland Park College.Oct. 11, '12		
*Idaho, Univ of..........June 25, '14		
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Lewis Institute..........Nov. 8, '07		
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*Washington, Univ. of..Dec. 13, '12		
*West Virginia Univ.....Nov. 13, '14		
*Worcester Poly. Inst...Mar. 25, '04		
Yale University........Oct. 13, '11		

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PROCEEDINGS

OF THE

American Institute of Electrical Engineers

Vol. XXXVIII
Number 2

FEBRUARY, 1919

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TABLE OF CONTENTS

Section I.—Institute Affairs

A. I. E. E. Seventh Midwinter Convention, February 19-21, 1919 55
Future A. I. E. E. Meetings 57
Future Section Meetings 57
A. I. E. E. Meeting in New York, January 10, 1919 57
A. I. E. E. Directors Meeting, New York, January 10, 1919 58
1919 Year Book 59
Collection of Data on Telephone Interference Factor 59
Engineering Council. A New Member Society 61
The John Fritz Medal for General Goethals, Awarded by Engineering Societies 61
National Research Council 62
Report of Patent Committee to the National Research Council 62
Standardization of Technical Symbols 63
Past Section Meetings 63
Past Branch Meetings 64
Associates Elected, January 10, 1919 64
Associates Reelected January 10, 1919 67
Members Elected January 10, 1919 67
Transferred to the Grade of Member, January 10, 1919 67
Transferred to the Grade of Fellow, January 10, 1919 68
Recommended for Transfer 68
Applications for Election 68
Students Enrolled 70
Addresses Wanted 71
Personal 72
Obituary 73
An Appeal to the Membership of the Institute 74
Engineering Service Bulletin 74
Accession to the Engineering Societies Library 78

Section II.—Papers and Reports

Aeronautics in the United States, 1918. By George O. Squier, New York, January 10, 1919 83
American Engineering Research. By W. R. Whitney, Philadelphia, Pa., December 13, 1918 115
Research in America after the War. By R. A. Millikan, Philadelphia, Pa., December 13, 1918 129
The Dielectric Strength of Air Films Entrapped in Solid Insulation and a Practical Application of the Problems for Alternator Coils and Cables. By F. Dubsky, New York, February 21, 1919. 141
Ionization of Occluded Gases in High-Tension Insulation. By G. B. Shanklin and J. J. Matson New York, February 21, 1919 163
Abnormal Voltages within Transformers. By L. F. Blume and A. Boyajian, New York, February 21, 1919 211

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PROCEEDINGS

Vol. XXXVIII FEBRUARY, 1919 Number 2

A. I. E. E. SEVENTH MIDWINTER CONVENTION

February 19-21, 1919

The Seventh Annual Midwinter Convention of the American Institute of Electrical Engineers will be held February 19-21, 1919, in the Engineering Societies Building, 33 West 39th Street, New York.

The Convention will open Wednesday afternoon in joint session with the American Institute of Mining Engineers, at which a symposium on "Electric Welding" will be presented. Members of the American Society of Mechanical Engineers are cordially invited to participate in this session.

Wednesday evening will be devoted to a lecture by Dr. John A. Brashear, on "An Evening with the New Astronomy," which will be followed by an exhibition of technical moving pictures as adopted by the U. S. War Department for the instruction of the army in the operation of various mechanical devices. The pictures will be accompanied by brief explanatory remarks. Ladies will be welcome at this session.

On Thursday morning there will be a technical session, opened by an address by President C. A. Adams, followed by the presentation of papers by Dr. C. P. Steinmetz and Mr. Harold S. Osborne, on subjects as announced in the program following.

Thursday afternoon will be devoted to a technical excursion to the Brooklyn Navy Yard, by courtesy of the Navy Department. Opportunities to visit the prominent electrical plants in New York and vicinity during the time of the Convention have also been provided. Details in regard to these trips are given under Technical Excursions

On Thursday evening there will be a Dinner-Dance at the Hotel Astor for members and guests in attendance at the Convention. Particulars in regard to this function will be found under the heading Entertainment

Friday morning's technical session is under the auspices of the Electrophysics Committee and papers will be presented by Messrs. G. B. Shanklin and J. J. Matson, by Mr. F. Dubsky, and by Messrs. L. F. Blume and A. J. Boyajian.

On Friday afternoon the final session of the Convention will be held under the auspices of the Telegraphy and Telephony Committee at which papers by the following authors will be presented: Messrs. E. B. Craft and E. H. Colpitts, Mr. J. R. Carson, and Mr. W. W. Crawford.

PROGRAM

WEDNESDAY AFTERNOON, FEBRUARY 19

AUDITORIUM, 2:30 P. M.

Joint Technical Session

1. *Microstructure of Iron Deposited by Electric Arc Welding*, by G. F. Comstock. (A. I. M. E.)
2. *Path of Rupture in Steel Fusion Welds*, by S. W. Miller. (A.I.M.E.)
3. *Welding Mild Steel*, by H. M. Hobart. (A. I. M. E.)
4. *Electric Welding in Shipbuilding*, by S. V. Goodall. (A. I. E. E.)
5. *Fusion in Arc Welding*, by O. H. Eschholz. (A. I. E. E.)

WEDNESDAY EVENING, FEBRUARY 19,
AUDITORIUM, 8:15 P. M.

Lecture

6. *An Evening With the New Astronomy*, by Dr. John A. Brashear. Ladies welcome.
7. *Technical Moving Pictures Showing Various Mechanisms in Operation.*

THURSDAY MORNING, FEBRUARY 20
ASSEMBLY ROOM NO. 1, 10:30 A.M.

Technical Session

8. Address, by President C. A. Adams.
9. *The General Equation of the Electric Circuit*, III, by C. P. Steinmetz.
10. *Review of Work of Sub-Committee on Wave-shape Standard, of the Standards Committee*, by H. S. Osborne.

THURSDAY AFTERNOON, FEBRUARY 20

Technical Excursion

Visit to Brooklyn Navy Yard, For details of trip see item, Technical Excursions, following.

THURSDAY EVENING, FEBRUARY 20,
HOTEL ASTOR, 7:00 P. M.

Dinner-Dance at Hotel Astor, For details see item, Entertainment, following.

FRIDAY MORNING, FEBRUARY 21,
ASSEMBLY ROOM NO. 1, 10:30 A. M.

Technical Session

11. *Ionization of Occluded Gases in High-Tension Insulation*, by G. B. Shanklin and J. J. Matson.
12. *The Dielectric Strength of Air Films Entrapped in Solid Insulation*, by F. Dubsky.
13. *Abnormal Voltage in Transformers*, by L. F. Blume and A. J. Boyajian

FRIDAY AFTERNOON, FEBRUARY 21,
ASSEMBLY ROOM NO. 1, 2:30 P. M.

Technical Session

14. *Radio Telephony*, by E. B. Craft and E. H. Colpitts.
15. *Theory of Transient Oscillations*, by John R. Carson.
16. *Telephone Circuits With Zero Mutual Induction*, by W. W. Crawford

ENTERTAINMENT

Dinner-Dance

A Dinner-Dance will be held at the Hotel Astor, Broadway and 44th Street, New York, Thursday evening, February 20, 1919, at 7:00 o'clock. The purpose of the dinner-dance is to provide a pleasant social function for the entertainment of the members and their guests in attendance at the convention.

The dinner will be served at 7:00 o'clock and prompt attendance is desired in order that the Entertainment Committee's arrangements may be carried out as planned.

The subscription price is $5.00 per person. This does not include wine, cigars, ciagrettes, or a late supper.

The tables will accommodate eight persons each. Members are requested to make up their own tables and to state their seating preference to the committee. Communications should be addressed to the Committee on Entertainment, A. I. E. E., 33 West 39th Street, New York. To assure satisfactory seating arrangements please advise as promptly as possible.

TECHNICAL EXCURSIONS

Special Excursion

Thursday afternoon, February 20, has been set aside by the Excursions Committee for a visit to the Navy Yard. Members and guests who desire to take advantage of this opportunity should indicate their intention to participate, at the A. I. E. E. registration desk at convention headquarters, promptly upon arrival at the building. It is planned to start from the Engineering Societies Building promptly at 1:30 p.m.

Inspection Trips

The following companies have courteously offered to open their plants for inspection by members and guests, either individually or in groups, on dates and at hours which will be announced in the final Program. The A. I. E. E. convention badge will be accepted as sufficient identification.

New York Edison Company—Waterside Power Stations, East 38th-40th Streets and First Avenue; Substation, 115-117 West 39th Street.

United Electric Light and Power Company—Power Station, 201st St. and Harlem River; Substation, Tremont Avenue and Watson Lane.

Interborough Rapid Transit Company—Power Station, 74th Street and East River; Substation, 57th Street, East of Lexington Avenue.

Electrical Testing Laboratories—80th Street and East End Avenue.

Laboratories of the Bell System—at Western Electric Company, 463 West Street. Chemical, Transmission Physical, Circuit, Radio Design, Research, Automatic, and Printing Telegraph Laboratories.

FUTURE A. I. E. E. MEETINGS

March Meeting.—The 348th meeting of the American Institute of Electrical Engineers will be held in Boston, Mass., on Friday March, 14, 1919. This meeting will be under the auspices of the Boston Section of the A. I. E. E. At the afternoon session there will be presented a paper entitled "Electromagnetic Theory of the Telephone Receiver with Special Reference to Motional Impedance" by A. E. Kennelly and H. Nukiyama. The evening session will be devoted to addresses on the general subject "Research."

April Meeting.—The 349th meeting of the Institute will be held at Institute headquarters, 33 West 39th St., New York on April 11, 1919. This will be a joint meeting under the auspices of the Lighting and Illumination Committee and in conjunction with the Illuminating Engineering Society. Mr. George H. Stickney will present the paper of the evening on "The Present Status of Industrial Lighting Codes in the United States."

May Meeting.—The 350th meeting of the Institute will be the Annual Business Meeting held at Institute headquarters, New York, May 16, 1919. At this meeting the annual report of the Board of Directors will be presented and announcement made of the election of officers for the ensuing year. The feature of chief interest at this meeting will be the ceremonies in connection with the presentation of the Edison Medal.

Annual Convention.—It has been decided to hold the 35th Annual Convention of the American Institute of electrical Engineers at the Lake Placid Club, Adirondacks, New York, during the week of June 23. Complete program and exact dates to be announced later.

FUTURE SECTION MEETINGS

Baltimore.—February 14, 1919. Subject: The Manufacture and Use of Toxic Gases in Modern Warfare." Speaker: Colonel William H. Walker.

Chicago.—February 24, 1919. Subject: Phenomena of Sound Waves. Speaker: John B. Taylor.

Philadelphia.—February 10, 1919, Engineers Club. Subject: The Importance of the Electrochemical Industry. Speaker: Prof. Jos. W. Richards.

Washington. — February 11, 1919. Cosmos Club. Subject: New Application of Electricity to Ships. Speaker: H. A. Hornor.

A. I. E. E. MEETING IN NEW YORK JANUARY 10, 1919

The 345th meeting of the American Institute of Electricial Engineers was held at Institute headquarters, 33 West 39th St., New York onJanuary 10, 1919. The evening was devoted almost exclusively to a lecture delivered by Major General George O. Squier, Chief Signal Officer of the United States Army on "Aeronautics in the United States." That the subject was one of intense interest to the engineering profession is instanced by the attendance of about 1100 members and guests.

President C. A. Adams, called the meeting to order at 8.40 p. m. In introducing General Squier he spoke of the enviable position of those who had been privileged to fight on the other side and of those who had the direction of the great efforts made. He pointed out the inability of people not intimately connected with affairs during the war to realize the character of the responsibility involved in such direction and the multitudinous and complicated problems that had to be solved, particularly in the new field of aeronautics over which General Squier presided.

Major General Squier then delivered his lecture which will be printed in full in a future issue of the PROCEEDINGS.

Succeeding the lecture a series of moving pictures was shown illustrating various phases of aircraft production and types of machines used. Capt Albro commented on the pictures as they appeared and furnished necessary explanations.

After a unanimous rising vote of thanks to General Squier proposed by Prof. Slichter the meeting adjourned at 10.30 p. m.

A. I. E. E. DIRECTORS' MEETING NEW YORK, JANUARY 10, 1919

The regular monthly meeting of the Board of Directors was held at Institute headquarters, New York, Friday, January 10, 1919, at 3:30 p. m.

There were present: President C. A. Adams, Cambridge, Mass.; Vice-Presidents W. B. Jackson, Chicago, F. B. Jewett, New York, John B. Taylor, Schenectady; Managers C. E. Skinner, Charles Robbins, and Wilfred Sykes, Pittsburgh, N. A. Carle, Newark, N. J., Walter A. Hall, Lynn, Mass.; Wm. A. Del Mar and W. I. Slichter, New York; Secretary F. L. Hutchinson New York.

The action of the Finance Committee in approving monthly bills amounting to $10,942.56, was ratified.

Chairman Slichter of the Meetings and Papers Committee reviewed the program of the Midwinter Convention.

The Board approved a meeting, including both afternoon and evening sessions, to be held in Boston, on Friday, March 14, subject to such arrangements as the Boston Section and the Meetings and Papers Committee may make.

Upon the recommendation of the Committee on Time and Place of Annual Convention, it was voted to hold the June 1919 Annual Convention at the Lake Placid Club, Lake Placid, N. Y.

A report was presented of the meeting of the Board of Examiners held December 30, 1918; and the actions taken at that meeting were approved.

Upon the recommendation of the Board of Examiners, the following action was taken upon pending applications: 78 Students were ordered enrolled; 77 applicants were elected to the grade of Associate; 3 applicants were reelected to the grade of Associate; 6 applicants were elected to the grade of Member; 9 applicants were transferred to the grade of Member; and 4 applicants were transferred to the grade of Fellow.

A proposed revision of the by-laws of the Standards Committee was submitted for approval; and it was voted to approve the by-laws as submitted.

The following representatives were appointed: Engineering Council—C. A. Adams and C. E. Skinner were reappointed, for a term of three years beginning February 1919; Board of Trustees, United Engineering Society —Dr. Samuel Sheldon was reappointed, for a term of three years beginning January 1919; Commission of Washington Award—Mr. John Price Jackson was reappointed, for a term of two years beginning January 1919.

A considerable amount of other business was transacted by the Board, reference to which will be found in this and future issues of the PROCEEDINGS.

1919 YEAR BOOK

The Institute Year Book for 1919 will be ready for distribution early in February and may be obtained free of charge by any member upon application to the Secretary, 33 West 39th Street, New York, by mail or otherwise.

This book contains in addition to the constitution, by-laws, lists of officers and committees, and considerable other general information relating to the activities of the Institute, an alphabetical and geographical catalogue of the membership corrected to January 1, 1919.

COLLECTION OF DATA ON TELEPHONE INTERFERENCE FACTOR

In a paper entitled, "Review of the Work of the Sub-committee on Wave Shape Standard of the Standards Committee," which appeared in the January PROCEEDINGS, an account is given of work which has led to the adoption of three new standardization rules regarding wave shape, standardization rules No. 407, 408 and 409. Rule No. 407 defines the telephone interference factor of a wave and rule No. 408 gives the physical basis for its evaluation. Rule No. 409 reads as follows:

> Limiting Value of Telephone Interference Factor.—A telephone interference factor (See paragraphs 17a and 407) of the open-circuit terminal voltage wave not exceeding ——— is permissible except when otherwise specified. This rule shall apply in cases where synchronous machinery is required for use in connection with open-wire transmission or distribution circuits and shall be supplementary to paragraph 406.* The purchaser shall in each case indicate whether or not the conditions are such that this section applies.

The Subcommittee on Wave Shape Standard of the Standards Committee wishes to obtain a large amount of further information before recommending any value to be inserted in rule No. 409 for use as a limit. This information should include data regarding the telephone interference factor on open circuit of synchronous machinery and also regarding the T. I. F. (telephone interference factor) of systems under ordinary operating conditions. The T. I. F. of individual machines and name plate data are desired to establish the relation between T. I. F. and construction of individual machines. The T. I. F. of systems on which these machines are operated is desired to establish the relation between T. I. F. of system and of individual machines connected thereto, which relation will be taken into account by the Committee in its recommendations.

Readings are desired at main generating stations and at important substations. The readings on individual machines should be on open circuit at rated speed and terminal voltage. As speed of the machine is an important factor of the T. I. F. the machine should be driven as near as possible to the rated speed and a record made of the actual speed. Two readings of the T.I.F. on open circuit should be made for each machine on different phases if possible.

The readings of T. I. F. of the system voltage should be made at hourly intervals over a complete 24-hour period. Since the readings depend on the nature of the load the data should include a record of the approximate character of the load, giving especial attention to loads such as rectifiers or electric furnaces which might have particularly important effects on the wave form. Also, the readings depend on the generating apparatus in use. Therefore, the data should identify all synchronous machinery connected to the system at the station at which the measurements are made and state the total load on that station.

The Subcommittee requests the cooperation of power operating engineers and others in the collection of these data. A few instruments for measuring the T. I. F. will be available for loan. Further information can be obtained from any member of the Subcommittee.*

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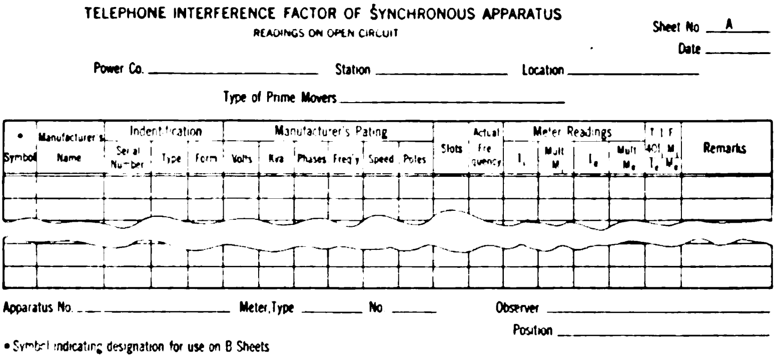
*Rule No. 406 relates to deviation factor as heretofore defined.

*The members of the Subcommittee are, C. A. Adams, Frederick Bedell, L. W. Chubb, A. W. Copley, F. M. Farmer, H. B. Gear, H. S. Osborne, L. T. Robinson and A. E. Silver.

Arrangements have been made for the cooperation of the Overhead Lines and Inductive Interference Committee of the National Electric Light Association and some of the electric manufacturing companies.

In the following paragraphs instructions are given for obtaining the desired readings and for using the apparatus for the measurement of telephone interference factor.



TELEPHONE INTERFERENCE FACTOR OF SYNCHRONOUS APPARATUS

READINGS ON OPEN CIRCUIT

Sheet No A

Date

Power Co. Station Location

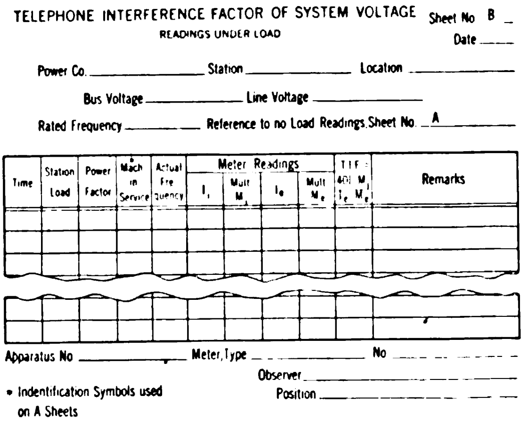
Type of Prime Movers

•	Manufacturer's	Indentification			Manufacturer's Rating							Actual	Meter Readings				T I F	Remarks
Symbol	Name	Serial Number	Type	Form	Volts	Kva	Phases	Freq'y	Speed	Poles	Slots	Frequency	I_1	Mult M_1	I_e	Mult M_e	401 M_1 I_e M_e	

Apparatus No. Meter, Type No Observer

Position

• Symbol indicating designation for use on B Sheets



TELEPHONE INTERFERENCE FACTOR OF SYSTEM VOLTAGE Sheet No B

READINGS UNDER LOAD

Date

Power Co. Station Location

Bus Voltage Line Voltage

Rated Frequency Reference to no Load Readings Sheet No. A

Time	Station Load	Power Factor	• Mach in Service	Actual Frequency	Meter Readings				T I F =	Remarks
					I_1	Mult M_1	I_e	Mult M_e	401 M_1 I_e M_e	

Apparatus No Meter, Type No

Observer

• Indentification Symbols used on A Sheets

Position

RECORD OF DATA

The attached record forms indicate the data which should be obtained in each case. Sheet "A" is for the open-circuit data and sheet "B" is for the system data. In some cases it may not be possible to give the actual frequency because of the lack of a reliable frequency indicator. In such cases the speed of the machine as obtained from a tachometer reading or speed count may be substituted. In any case it is desirable to check with a speed count the indications of the frequency meter.

The form for recording the readings on open circuit provides space for the name plate data of the machine. In case information given on the name plate does not correspond to the headings of the columns, these may be altered to fit the actual conditions. This applies particularly to the columns headed "Type" and "Form." Space is provided on this form for the number of slots in the armature winding of the machine for use when such information is available.

A general statement of the character of the load should be given on the back of the data sheet which records the readings under load. In case the load is mainly of one particular sort, such as synchronous motor-generator sets, synchronous converters or induction motors, this should be noted. If there are any large rectifier or electric furnace loads, their magnitude and location relative to the station where the telephone interference factor measurements are made should be given. Important changes in the character of the load should be noted in the column headed "Remarks."

METHOD OF MEASUREMENT

The pair of terminals on the top of the apparatus marked "Line" should be connected to the secondary of the potential transformer. If one side of this secondary circuit is grounded the "Line" terminal marked *Lg* should be connected to this side. The pair of terminals marked "Meter" should be connected to the measuring instrument.

When making an observation with the apparatus the dial switch marked "Multiplier for Meter" on the top should first be set at the value marked "40" before depressing the key which places the measuring instrument in the circuit. In case the deflection obtained is too small the key should be released and the dial switch set at the next value and so on until a satisfactory deflection is obtained. No switching either in the circuit external to the apparatus or with the switches on the top should be done while the key is depressed.

To obtain a value of the telephone interference factor the currents in the meter for the two positions of the double-throw double-pole switch should be read and recorded, together with the values of the multipliers used. These current readings are denoted I_e and I_i for the "Voltage" and "Current" positions, respectively, of the switch. If the settings of the multiplier dial switch be denoted M_e and M_i respectively, the telephone interference factor is given by the expression.

$$\text{T. I. F.} = 40 \frac{I_i\ M_i}{I_e\ M_e} \text{ microamperes}$$

per volt.

This expression follows from the definition of the telephone interference factor as the ratio of the current in the meter branch of the network in microamperes to the potential across the network terminals in volts. $I_i\ M_i$ is the current in the meter branch of the network and $I_e\ M_e$ the current in a 25000-ohm resistance across the network terminals, both expressed in milliamperes. Hence the current in microamperes is 1000 $I_i\ M_i$ and the potential in volts 25 $I_e\ M_e$. The ratios is thus

$$\frac{1000\ I_i\ M_i}{25\ I_e\ M_e} = 40 \frac{I_i\ M_i}{I_e\ M_e}$$

which is the expression given above.

ENGINEERING COUNCIL

A New Member Society

American Society for Testing Materials has accepted an invitation to become a member of Engineering Council. All formalities have been completed and this Society is now in full membership. Its representative is expected to take his place in the Annual meeting, February 20. The member societies of Engineering Council are now: American Society of Civil Engineers, American Institute of Mining Engineers, American Society of Mechanical Engineers, American Institute of Electrical Engineers, American Society for Testing Materials, United Engineering Society.

THE JOHN FRITZ MEDAL FOR GENERAL GOETHALS

Awarded by Engineering Societies

The John Fritz Medal Board of Award, composed of representatives of the National Societies of Civil, Mining, Mechanical and Electrical Engineers, held their annual meeting for 1919 at the Engineers' Club, Friday evening, January 17th, and awarded their gold medal to George W. Goethals, the builder of the Panama Canal.

The medal has previously been awarded to Lord Kelvin, George Westinghouse, Alexander Graham Bell, Thomas A. Edison, Charles T. Porter, Alfred Noble, Sir William Henry White, Robert W. Hunt, John Edson Sweet, James Douglas, Elihu Thomson, Henry M. Howe and J. Waldo Smith.

Col. John J. Carty, now in France, has been Chairman of the Board, but in his absence Ambrose Swasey, of Cleveland, presided.

George H. Pegram has been elected Chairman for 1919 and W. F. M. Goss, Treasurer, in place of Prof. F. R. Hutton, who died during the year.

NATIONAL RESEARCH COUNCIL

At the University Club, New York, January 23, Chairman George E. Hale and other officers of the National Research Council, gave a dinner to officers of the National engineering and other societies. About thirty persons were present, including officers of National Research Council, the four Founder Societies, American Society for Testing Materials, Society of Automotive Engineers, Inc., Illuminating Engineering Society, United Engineering Society and Engineering Foundation. Letters were received from the Western Society of Engineers, which also had been invited. Gano Dunn, Vice-Chairman of National Research Council, was toastmaster.

Dr. Hale outlined the proposed permanent organization of the National Research Council and possible methods of connection with the National engineering societies, either directly or through Engineering Foundation. In the permanent organization of the Engineering Division of National Research Council, it was suggested that not only the four Founder Societies should have a part, but also the other National engineering societies admitted to membership in Engineering Council.

The toastmaster called upon many representatives of the societies for opinions. Among the sentiments prominently expressed were the following:

1. That there should be close union between Engineering Foundation and the Engineering Division of the National Research Council without submerging the identity of either.

2. That Engineering Foundation should contribute to the financial support of the Engineering Division.

3. That the headquarters of the Engineering Division should be in Engineering Societies Building, New York.

4. That the Engineering Division should have as chairman, an engineer of the highest professional attainments and wide reputation, who should devote his whole time to the development and establishment of the Division.

5. That the Industrial Relations Division, also, should have offices in Engineering Societies Building, New York.

REPORT OF PATENT COMMITTEE OF NATIONAL RESEARCH COUNCIL

In response to a request of the Commissioner of Patents in 1917 and with the approval of the Secretary of the Interior, a Patent Committee was appointed by the National Research Council to investigate the Patent Office and patent systems with a view to increasing their effectiveness and usefulness to the industrial life of the country. The Committee appointed by the National Research Council consisted of Dr. William F. Durand, Chairman, Drs. Leo H. Baekeland, M. I. Pupin, R. A. Millikan, S. W. Stratton, Reid Hunt, and Messrs. Frederick P. Fish, Thomas Ewing and Edward J. Prindle. In the absence of Dr. Durand in Europe Dr. Baekeland was appointed Acting Chairman.

This Committee has recently submitted a report which has the concurrence of the Patents Committee of the Engineering Council. This report proposed a program consisting of three features, which are as follows:

1. Single court of patent appeals.
2. Making the Patent Office a separate institution independent of the Department of the Interior.
3. Providing an increase in force and salaries of the Patent Office.

The report gives arguments at considerable length showing the advantages which would accrue through the adoption of these three proposals.

The report also contains a recommendation with reference to compensation for infringement of patents. Under the present law while an injunction can be obtained against an infringer in a case where a patent has been adjudged valid, a money recovery has not been possible except under most favorable circumstances, and the Committee therefore proposes that the law be amended so that the court, on due proceedings, may adjudge payment of a reasonable royalty or other form of general damages to the complainant.

Three proposed bills covering the recommendations of the Committee accompany the report.

STANDARDIZATION OF TECHNICAL SYMBOLS

A conference for the standardization of technical symbols has been organized consisting of the Committee on Nomenclature of the Society for the Promotion of Engineering Education with the addition of delegates appointed by other national societies. Among the societies represented are the American Institute of Electrical Engineers, American Society of Mechanical Engineers, American Institute of Mining Engineers, Society of Automotive Engineers, and American Society of Civil Engineers. The first meeting of the conference was held in New York City, December 1918, at which meeting Prof. John T. Faig was elected Chairman, and Mr. Sanford A. Moss, Temporary Secretary. It was agreed that the conference should be enlarged by the addition of delegates from all other national societies which might be interested. Each society has been asked to send in a list of symbols in common use in its own field before February 1st, in order that the symbols may be compiled and charted for presentation at a meeting to be held as soon after February 1st as is feasible. Members of the A. I. E. E. who are interested in the standardization of technical symbols are invited to write the representative of the A. I. E. E., Mr. George R. Metcalfe, 33 West 39th Street, presenting their ideas for consideration at the conference.

PAST SECTION MEETINGS

Boston.—January 7, Chipman Hall, Tremont Temple. Illustrated address by Mr. M. Luckiesh on "Camouflage on Land, Sea and Air." Joint meeting with Boston Section of Illuminating Engineering Society. Attendance 300.

Chicago.—December 30, 1918, Western Society Rooms. Address by President Comfort A. Adams on "Electric Welding in Ship Building." Attendance 325.

Cleveland.—December 16, 1918, Nela Park. Illustrated address by Mr. John E. Randall on "The History and Development of Incandescent Electric Lamps." Motion pictures were shown of the various processes in lamp manufacture. Attendance 95.

Detroit—Ann Arbor.—December 27, 1918, Detroit Board of Commerce. Paper: "Alternating Current Circuits" by H. H. Higbie. Attendance 30.

January 10, 1919, Detroit Board of Commerce. Paper: "Development of Industrial Control" by H. D. James. Attendance 75.

Lynn.—January 8, 1919, G. E. Hall. Lecture by Mr. Robert P. Burrows on "Motion Picture Projection." Attendance 107.

Pittsfield.—December 19, 1918, New American Hotel. Illustrated lecture on "The Manufacture of the Modern

Incandescent Lamp." by Mr. A. L. Powell. Attendance 175.

Portland.—December 3, 1918, Gasco Building. Paper: "Electric Smelting" by W. L. Morrison. Attendance 40.

Rochester.—December 20, 1918, Rooms of Rochester Engineering Society. Paper: "Increased Production by Correct Illumination" by F. C. Taylor. Attendance 40.

Schenectady.—December 20, 1918, Edison Club Hall, Illustrated address by Mr. A. H. Armstrong on "Steam Road Electrification." Attendance 245.

January 3, 1919, Edison Club Hall. Lecture by Mr. C. A. Kelsey on "The Sugar Industry." Moving pictures entitled "Cuba, the Island of Sugar." Attendance 165.

Seattle.—December 17, 1918, Arctic Club Building. Paper: "Electric Welding —A New Industry" by H. A. Hornor. Attendance 29.

Washington.—December 10, 1918, McKinley Memorial Training School. Address by Lieut. Col. John H. Finney on " Experiences Abroad in the Study of Zeppelins." Attendance 47.

January 14, 1919, Cosmos Club. Address by Mr. N. W. Storer on "Electrification of Steam Railroads." Attendance 75.

PAST BRANCH MEETINGS

University of California.—November 27, 1918, Mechanics Building. Paper: "The Electric Gyroscope and Its Application to Marine Work" by A. E. Mc Mahon.

December 11, 1918, Mechanics Building, Paper: "The Operating Characteristics of Vacuum Tube Apparatus" by L. M. K. Boelter.

Virginia Polytechnic Institute.—January 14, 1919. Election of officers as follows—chairman, J.A.Carr; secretary-treasurer, L. D. Fry; executive committee Professors S. R. Pritchard and C. Lee, and Messrs. A. W. Fairer, R. C. Smith and E. W. Bryant.

University of Virginia.—January 15, 1919, Electrical Laboratory. Election of officers as follows—J. E. B. Stuart, chairman; J. A. Evans, secretary; executive committee, Prof. W. S. Rodman and Messrs. H. L. Painter and G. C. Boyer. Address by Prof. W. S. Rodman on "Benefits Derived from the A. I. E. E."

Washington University.—December 11, 1918. Election of officers as follows—Dean A. S. Langsdorf, honorary chairman; Walter J. Sprainka, chairman; A. Murphy, vice-chairman; Harold T. Lange, secretary-treasurer; N. Sprainka engineers council representative.

State College of Washington.—January 10, 1919, Mechanic Arts Building. Paper: "Electrical Development in the West" by J. W. Beyer. Attendance 19.

University of Washington.—January 7, 1919. Paper: "The Future Demands in the Engineering Field" by Mr. Crawford. Attendance 22.

ASSOCIATES ELECTED JANUARY 10, 1919

*BAKER, WALTER R. G., Electrical Engineer, Standardizing Laboratory, General Electric Co.; res., 1 James St., Schenectady, N. Y.

BALDWIN, JOHN ROBINSON, Engineer, Testing Section, Engineering Dept., Georgia Railway & Power Co., 456 Gas-Electric Bldg., Atlanta, Ga.

BARRETT, JOSEPH R., Chief Draftsman, Switchboard Dept., Condit Electrical Mfg. Co.; res. 674 Second St., So. Boston, Mass.

BEERSTECHER, LEONARD H. C., Construction Foreman, Construction Dept., General Electric Co., Schenectady, N. Y.

BERG, LOUIS, Electrician, Great Northern Railway Co.; res., 610 1st Ave. North, Great Falls, Mont.

BERGMANN, CARL A., Engineer, Searchlight Dept., Sperry Gyroscope Co.; res., 263-75th St., Brooklyn, N. Y.

BROBST, JOHN E., Asst. Engineer, Industrial Control Dept., General Electric Co.; res., 21 Elder St., Schenectady, N. Y.

Burr, Clifford B., Electrical Contractor, 100 Main St., Ansonia; res., Academy Hill, Derby, Conn.

Campbell, Arthur Ballard, Testing Engineer, General Electric Co.; res., 1860 Lindley Ave., Ft. Wayne, Ind.

Carlson, Wendell L., Radio Electrician, Radio Test Shop, Navy Yard; res., 805 B. St., S. E., Washington, D. C.

Chapman, Fred Elton, Assistant Engineer, Bangor Railway & Electric Co., Bangor; res., Carmel, Maine.

Chow, G., Engineering Apprentice, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 915 Ross Ave., Wilkinsburg, Pa.

Cook, Charles Grant, Mechanical & Electrical Engineer, 498 Union St., Aberdeen, Scotland.

Dixon, Olan R., Electrician, Coast Steel & Machinery Co.; res., 474 Lexington Ave., Portland, Ore.

Elzi, Joseph A., Instructor in War Training, University of Colorado; res., 1035 Arapahoe Ave., Boulder, Colo.

Evelev, Yale, Engineering Office, Turners Falls Power & Electric Co., Greenfield, Mass.

Fehrlin, Earl Milton, Tester, Diehl Mfg. Co., Elizabethport; res., 19 Sayre St., Elizabeth, N. J.

Folline, William Benjamin, Student Engineer, General Electric Company; res., 110 Front St., Schenectady, N.Y.

Frogner, George Alvin, Field Engineer, Supply Div., Emergency Fleet Corp., 1330 Northwestern Bank Bldg., Portland, Ore.

Goldberg, Samuel, Sub-Inspector (Electrical), Bureau of Steam Engineering, U. S. N., N. Y. Shipbuilding Corp., Camden, N. Y.

Graeff, Wilmer Keller, Electrical Expert, Diehl Mfg. Co.; res., 533 Muriel Parkway, Elizabeth, N. J.

Grandage, Herbert, Jr., Elec. Engr. & Asst. to Industrial Engineer, The Baird Machine Co., Bridgeport; res., 3315 Main St., Stratford, Conn.

Hall, William Arthur, Chief Electrician, Consolidated Arizona Smelting Co., Humboldt, Arizona.

Hansen, Carl C. L., Chief Electrician, American Smelter & Refining Co.; res., 4629 So. State St., Murray, Utah.

Harshaw, Henry M., Gen. Supervisor of Charging Stations, E. I. Du Pont de Nemours & Co., Hopewell, Va.

***Harwood, Paisley B.**, Electrical Engineer, Cutler-Hammer Mfg. Co.; res., 2443 Sycamore St., Milwaukee, Wis.

Housley, J. Elmer, Electrical Dept., Aluminum Ore Co.; res., 607 Veronica St., E. St. Louis, Ill.

Hughes, Joseph Earl, Instructor of Electricity, School of Engineering; res., 1226 14th Street, Milwaukee, Wis.

***Hutchinson, William Martin**, Control Engr., Railway Div., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Kennedy, John Joseph, Elec. Construction Foreman, Chile Exploration Co., Chuquicamata, Chile, A. S.

Kettle, Arthur Stafford, Chief of Testing Dept., British Thomson-Houston Co. Ltd.; res., The Old Hall, Clifton, Rugby, England.

Kewer, Leslie John, Shipwright, Fore River Shipbuilding Corp., Quincy; res., 139 Spencer St., Dorchester, Mass.

***King, Harvey**, Service Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 496 Ella St., Wilkinsburg, Pa.

King, Robert, Electrician, Southern States ElectricCo.;res., 2727 3rd Ave. North, Birmingham, Ala.

***Kingsley, Chester Ward**, Instructor in Naval Aviation, Detachment of Elec. Work, Mass Inst. of Tech., Cambridge, Mass.

Kneppers, Joseph M., Engineers, Messrs. Harrisons & Crosfield Ltd., Batavia, Java.

Knierim, William H., Cadet Engineer, The New York Edison Co., 15th St. and Irving Pl., New York, N. Y.

Koyanagi, Skeji, Elec. Engr., Nagasaki Works, Mitsubishi Shipyard & Engine Works, Nagasaki, Japan.

Kretschmer, Alfred Arnold, Special Electrician, South Works of Illinois Steel Co.; res., 7810 Marquette Ave., Chicago, Ill.

Kruecke, Grover Ernst, Asst. Elec. Instructor, Electrical Laboratory, School of Engineering of Milwaukee; res., 705 1st St., Milwaukee, Wis.

*Lewis, Howard W., In Charge Radio Laboratory, Mare Island Navy Yard; res., 740 York St., Vallejo, Cal.

Lloyd, Will L., Jr., Laboratorian, General Electric Co.; res., Woodlawn Inn, Pittsfield, Mass.

Lush, Arthur John, Manager & Representative, Robert W. Paul, 1 East 42nd St.; res., 3109 Sedgewick Ave., New York, N. Y.

Maercker, Alex. Carl, Transmission & Protection Engineer, Wisconsin Tel. Co.; res., 313 18th St., Milwaukee, Wis.

Marchant, Edgar A., Tester of Electrical Machinery & Steam Turbines, General Electric Co., W. Lynn; res., 48 Dimick St., Somerville, Mass.

*Mayeda, Isamu, Student Engineer, Testing Dept., General Electric Co., Schenectady; res., 147 Riverside Ave., Scotia, N. Y.

McDaniel, Alexander H., Electrical Engineer, Atlas Powder Co., Wilmington, Del.; res., North East, Cecil Co., Md.

*McKinley, Howard Waldo, Aerial Gunning School, Taliaferro Field, Fort Worth, Texas; res., Ault, Colo.

Mentzel, Jesse Grant, Electrical Tester & Electrician, Diehl Mfg. Co., Elizabethport; res., 124 Elizabeth Ave., Newark, N. J.

*Merris, Carl Elmer, Engineer in Research Section, Switchboard Dept., General Electric Co.; res., 334 Germania Ave., Schenectady, N. Y.

Morgan, Herbert G., Signal Engineer, Illinois Central R. R.; res., 6823 Harper Ave., Chicago, Ill.

*Norris, Ferris Waldo, Student Engineer, Testing Dept., General Electric Co.; res., 410 Schenectady St., Schenectady, N. Y.

Norton, Leland Davis, Consulting Engg. Laboratory, General Electric Co.; res., 410 Schenectady St., Schenectady, N. Y.

*Oliphant, Abner Chambers, Asst. Head, Gauge Branch, Inspection Div., Ordnance Dept., Washington D. C.; res., 805 Greenwood Ave., Trenton, N. J.

Parske, Charles F., Instructor, School of Engineering of Milwaukee; res., 132 Concordia Ave., Milwaukee, Wis.

Polstrock, Louis B., Asst. to Manager of Overhead Construction, Westinghouse Elec. & Mfg. Co., 1442 Widener Bldg., Philadelphia, Pa.

Price, Clarence Albert, Engineer, Canadian Westinghouse Co. Ltd.; res., 151 Sanford Ave. South, Hamilton, Ont., Canada.

Redman, Frank McIntosh, Application Engineer, Westinghouse Elec. & Mfg. Co., 1014 Northwestern Bank Bldg. Portland, Ore.

Roderick, Arthur Thomas, Electrical Engineer, Woodward Electric Company; res., 14 Auburn Ave., Atlanta, Ga.

Santos, João Noronha, Managing Director, Companhia Linha Circular de Bahia, Victoria 22, Bahia, Brazil, S. A.

Shohan, Abraham, Electrical Engineer, Public Works Dept., Navy Yard, Boston; res., 6 Dennison St., Roxbury, Mass.

*Siegmund, Humphreys Oliver, Teacher, Electrical Engineering, Drexel Institute, Philadelphia, Pa.

Silverman, Isaac D., Electrical Designer, Interborough Rapid Transit Co., 600 W. 59th St.; res., 911 East 176th St., New York, N. Y.

Smith, Nelson Ernest, Supt. of Distribution, Blackstone Valley Gas & Electric Co.; res., 67 Maple St., Woonsocket, R. I.

Solinsky, Irving, Electrical Foreman, of Construction, Westinghouse, Church, Kerr Co., New York, N. Y.; res., 24 Willow St., Bayonne, N. J.

STEWART, EMERY CHARLES, Tester, General Electric Co., Lynn; res., 28 Laurel St., West Lynn, Mass.

SUTHERLAND, WILLIAM FRANK, Editor, Technical Magazines, MacLean Publishing Co., 143 University Ave,. Toronto, Ont., Canada.

TAYLOR, CHESTER WARREN, Electrical Engineer, Sargent & Lundy, 1412 Edison Bldg., Chicago, Ill.

*THALHEIMER, JOHN JOSEPH, Designing Engineer, A. C. Engg. Dept., General Electric Co.; res., 418 Schenectady St., Schenectady, N. Y.

TORRACA, JOSEPH P., Chief Operator, Air Nitrates Corp., Muscle Shoals, Ala; res., 72 Baxter St., New York, N. Y.

VICARY, EDWARD HENRY, Electrical Supt., Whalen Pulp & Paper Co., Port Alice, B. C., Canada.

VILLASUSO, ARMANDO S., Chief Electrician, Cuba Cane Sugar Co., Central Moron, Pina, Camaguey, Cuba.

*WALTHERS, WILLIAM KEARNEY, Sales Engineer & Manager, Chicago Office, Mechanical Applicance Co., 327 So. La Salle St., Chicago, Ill.

WANG, WEN TSAU, Asst. Engr. in charge of Electrical Section, Hanyang Iron & Steel Works, Hanyang, China.

WERWATH, OSCAR, President, School of Engineering of Milwaukee, 373 Broadway; res., 792 Racine St., Milwaukee, Wis.

WESTERMAN, RODOLPHO, Engineering Dept., Electric Machinery Co.; res., 1605 Elliot Ave., Minneapolis, Minn.

WILLIAMS, EDWARD J., Engineering Inspector, Bell Telephone Co. of Pa., 416 7th Ave., Pittsburgh, Pa.

*Former enrolled Students

Total 77

ASSOCIATES RE-ELECTED JANUARY 10, 1919

CREGO, S. M., Commercial Engineer, General Electric Co., New York; res., 498 Macon St., Brooklyn, N. Y.

EMERY, LOREN, Special Rep., Foreign Dept., General Electric Co.; res., 3 South McClellan St., Schenectady, N. Y.

HARRIS, C. R. R., Electrical Engineer, Kerite Insulated Wire & Cable Co., 30 Church St., New York, N. Y.

MEMBERS ELECTED JANUARY 10, 1919

CAMPBELL, FRED R., Treasurer, Campbell Electric Co., 17 Stewart St.; res., 51 Bay View Ave., Lynn, Mass.

DOUGLASS, CHARLES HENRY, Electrical Engineer, Motor Dept., GeneralElectric Co., Lynn; res., 165 Burrill St., Swampscott, Mass.

EINHART, CARL M., Manager & Secretary, Roswell Gas & Electric Co.; res., 212 N. Kansas Ave., Roswell, New Mexico.

MORRISON, MONTFORD, Consulting Engineer, Victor Electric Corp., 236 So. Robey Street, Chicago, Ill.

SPENCER, MILLARD COLE, Electrical Engineer, Crocker-Wheeler Co., Ampere; res., 56 Stockton Place, E. Orange, N. J.

TEAGUE, NEWTON NESBITT, 2nd Lieut., Air Service Section, U. S. A., 1201 Lamar Building, Augusta, Ga.

TRANSFERRED TO THE GRADE OF MEMBER JANUARY 10, 1919

AGNEW, PAUL G., Physicist, Bureau of Standards, Washington, D. C.

BARNERT, MEYER,Power Sales Engineer & Industrial Engineer, Northern States Power Co., Minneapolis, Minn.

DOSTAL, JOHN F., General Manager, Colorado Springs Light, Heat & Power Co., Colorado Springs, Colo.

FAHY, FRANK P., Consulting Magnetic Engineer, New York, N. Y.

GARDETT, HELMUTH C., Assistant Electrical Engineer, Bureau of Power & Light, Dept. of Public Service, Los Angeles, Cal.

GUTTING, LEO A., Manager, Southern Indiana Power Co. and Interstate Public Service Co., Bedford, Ind.

Oesterreicher, Sandor I., Electrical Engineer with T. E. Murray, New York, N. Y.

Parrott, Robert P., Special Representative, Edison Lamp Works of G. E. Co., Harrison, N. J.

Swanstrom, Frank N., Chief Engineer, Electric Machinery Co., Minneapolis, Minn.

TRANSFERRED TO THE GRADE OF FELLOW JANUARY 10, 1919

Cohen, Louis, Consulting Engineer, Signal Corps, U. S. A.; Professor, Radio Engineering, George Washington University, Washington, D. C.

Lawton, Arthur H., Asst. Chief Engineer and Manager, Construction Dept., Consumers Power Co., Jackson, Mich.

Ricker, Charles W., Assistant General Manager and Chief Engineer, Havana Electric Railway, Light & Power Co., Havana, Cuba.

Staege, Stephen A., General Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its regular monthly meeting held on January 27, 1919, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

Frank, John J., Asst. Engineer, Transformer Dept., General Electric Co., Pittsfield, Mass.

To Grade of Member

Bush, Vannevar, Consulting Engineer, American Radio & Research Corp., Medford Hillside, Mass.

Dubilier, William, Consulting Engineer, New York, N. Y.

Falkenburg, Eugene L., Supt. of Power, Riegos y Fuerza del Ebro, Barcelona, Spain.

Harbin, George F., Electrical Engineer, Washington Terminal Co., Washington, D. C.

Scott, Carl F., Manager, Specialty Apparatus Sales, Sprague Electric Works, New York, N. Y.

Simon, Emil J., Radio Engineer, New York, N. Y.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before February 28, 1919.

Abbott, A. H., St. Paul, Minn.
Abrahams, S. L., Lynn, Mass.
Alger, E. C., (Member), Bethlehem, Pa.
Allen, F. J., Toronto, Ont.
Almquist, F. G., New York, N. Y.
Bakke, T. T., Schenectady, N. Y.
Barrett, C. F., Brooklyn, N. Y.
Barrows, L. D., New York, N. Y.
Bascom, H. M., (Member), New York, N. Y.
Behr, H. R., Chicago, Ill.
Bliziotis, G. E., Newark, N. J.
Bodde, T., Lynn, Mass.
Britt, J., New York, N. Y.
Broadberry, W., Mt. Union, Pa.
Brooks, H. T., Nashville, Tenn.
Broome, W. G., Madison, Wis.
Buell, F. T., Chicago, Ill.
Bullington, L. C., E. Pittsburgh, Pa.
Burton, E. F., Toronto, Ont.
Bussey, R. E., Newport News, Va.
Cammack, J. E., Washington, D. C.
Campbell, F. C., Schenectady, N. Y.
Candlish, B., Niagara Falls, Ont.
Carr, C. K., Chicago, Ill.
Carson, J. R., New York, N. Y.
Casal, F. M., Jr., San Francisco, Cal.
Clark, A. B., (Member), New York, N. Y.

Clark, B. L., (Member), Bethlehem, Pa.
Clark, E. L., Schenectady, N. Y.
Clyde, W. W., Storrs, Carbon Co., Utah
Cockaday, L. M., Yonkers, N. Y.
Cole, H., Detroit, Mich.
Coley, W. R., Philadelphia, Pa.
Colien, F. E., Johnstown, Pa.
Collier, D. C. Stithton, Ky.
Courser, C. H., (Member), Houston, Texas.
David, L. I., New York, N. Y.
Davidson, J., Jr., New York, N. Y.
Davidson, J. A., Chicago, Ill.
Demarest, C. S., New York, N. Y.
Demmerle, W. F., Brooklyn, N. Y.
De Salis, H. W., Hamilton, Ont.
Dickie, D. P., New York, N. Y.
Dickinson, J. A., Washington, D. C.
Dontopoulos, J. T., San Francisco, Cal.
Dooley, J. J., Lyndhurst, N. J.
Doughty, W. E., Detroit, Mich.
Dressner, V. D., Brooklyn, N. Y.
Eggers, H. C. T., New York, N. Y.
Elliott, J. W., E. Pittsburgh, Pa.
Essick, L. F., Schenectady, N. Y.
Estabrook, R. F., New York, N. Y.
Faram, S. T., Toronto, Ont.
Fauquex, A., New York, N. Y.
Folk, G. E., (Member), New York, N.Y.
Furlong, T. A., Milwaukee, Wis.
Granfield, T. H., Minneapolis, Minn.
Grove, H. S., New York, N. Y.
Habel, F. L., Detroit, Mich.
Hall, A. G., Toronto, Ont.
Hanley, J. F., Boston, Mass.
Harris, P. L., Kearny, N. J.
Harrison, H. C., New York, N. Y.
Harvey, H. F., Jr., Schenectady, N. Y.
Healy, F. C., New York, N.Y.
Hodgins, L. J., College Park, Md.
Holden, E. A., Philadelphia, Pa.
Hopkins, R. A., (Member), Boston, Mass.
Hotopp, A. H., New York, N. Y.
Hudspeth, C. C., E. Pittsburgh, Pa.
Jacobus, C. R., Salt Lake City, Utah
James, F. E., Schenectady, N. Y.
Kalaway, J. A., Pittsburgh, Pa.
Kelly, J. B., New York, N. Y.
Kerr, A. M., Akron, Ohio
Keyes, D. H., New York, N. Y.
Klopsteg, P. E., (Member), Philadelphia, Pa.
Kuehl, F. A., Boston, Mass.
Kuhn, G. W., New York, N. Y.
Lansil, E. F., Boston, Mass.
Lawson, H. J., Phoenix, Ariz.
Long, C. C., New London, Conn.
Lowry, H. H., Chicago, Ill.
Lynn, C., Lawrence, Kansas
MacDonald, R. Q., Tonopah, Nev.
Macias, C., Mexico, D. F., Mex.
Mansfield, H., Bridgeport, Conn.
Marshall, R. C., Jr., (Member), Washington, D. C.
Maynard, C. T., Rumford, Me.
Mayo, A., Pittsburgh, Pa.
McClure, M. B., (Member), Atlanta, Ga.
McKown, F. W., New York, N. Y.
McQuade, W. J., New York, N. Y.
Miles, J. G., E. Pittsburgh, Pa.
Miller, J. H., Chicago, Ill.
Mills, N. C., (Member), Peterboro, Ont.
Moll, H. I., Camp Meade, Md.
Moody, P. R., (Member), Lowell, Mass.
Moore, H. R., Chicago, Ill.
Moore, J. H., New York, N. Y.
Mueller, C. H., Pittsburgh, Pa.
Myers, S. G., Brooklyn, N. Y.
Neill, E. L., San Francisco, Cal.
Newman, J. D., Hog Island, Pa.
Newton, W. T., San Francisco, Cal.
Nixon, H., Chicago, Ill.
Noda, G., New York, N. Y.
Noda, S., New York, N. Y.
O'Donohue, J. P., New York, N. Y.
Palmer, W. W., (Member), Opelika, Ala.
Pearson, J. T., Detroit, Mich.
Perlewitz, J. M., Salt Lake City, Utah
Perry, A., Staten Island, N. Y.
Peters, F. W., Schenectady, N. Y.
Peyton, J. T., E. Pittsburgh, Pa.
Phinney, E. A., Golden, Colo.
Pierce, R. E., New York, N. Y.
Pouillon, M. J., New York, N. Y.
Pyke, D. C., Indianapolis, Ind.
Reed, W. C., Pittsfield, Mass.
Reed, W. R., Cohoes, N. Y.
Rice, A. R., Toronto, Ont.
Riley, H. Z., New Haven, Conn.
Rodda, M. H., Philadelphia, Pa.
Rogers, T. I., New York, N. Y.
Rose, A. F., New York, N. Y.
Rose, C. C., New York, N. Y.

Sakamoto, J., Pittsburgh, Pa.
Salsbury, R. J., Pittsburgh, Pa.
Sanders, H. M., E. Pittsburgh, Pa.
Schafer, C. G., Philadelphia, Pa.
Seibel, C. F., Jr., New York, N. Y.
Shapiro, N., Philadelphia, Pa.
Sherwood, W. R., New York, N. Y.
Siebert, L., San Francisco, Cal.
Sill, E. T., E. Pittsburgh, Pa.
Simonds, H. F., Pensacola, Fla.
Singleton, L. DeL., E. Pittsburgh, Pa.
Sly, E. E., Erie, Pa.
Sly, J. A., Portland, Ore.
Smith, C. M., Chicago, Ill.
Smith, E., New York, N. Y.
Smith, E. R., Washington, D. C.
Smith, P., (Member), Bangor, Me.
Soderholm, A. E., Rochester, N. Y.
Sparks, J. D., Salt Lake City, Utah
Stahl, G. D., Philadelphia, Pa.
Stanton, I. B., Newark, N. J.
Stearns, C. E., Camden, N. J.
Stenerwald, J. J., Hog Island, Pa.
Storrow, J. T., Jr., New York, N. Y.
Stoute, E. V., E. Pittsburgh, Pa.
Strandell, J. G. A., Chicago, Ill.
Taff, C. E., Pittsburgh, Pa.
Thoms, L. W., Detroit, Mich.
Thompson, G. K., New York, N. Y.
Thuener, O. C., Schenectady, N. Y.
Tolmie, J. R., Puget Sound, Wash.
Toomey, J. F., New York, N. Y.
Tree, E. W., New York, N. Y.
Tsumori, E., Schenectady, N. Y.
Van Asperen, C. H., Toronto, Ont.
Vernam, G. S., New York, N. Y.
vom Steeg, E., Jr., New York, N. Y.
Walther, J. T., Kenmore, Ohio
Way, D. D., Elizabethport, N. J.
Waterman, C. C., New York, N. Y.
Watson, E. F., New York, N. Y.
Weir, J., Somerville, Mass.
Weissinger, H., Philadelphia, Pa.
Wheelock, F. O., San Francisco, Cal.
Whitworth, G. K., San Francisco, Cal.
Wildman, L. A., Peoria, Ill.
Williams, E. C., New York, N. Y.
Williams, W. R., New York, N. Y.
Winchester, B. S., New York, N. Y.
Wood, H. B., Boston, Mass.
Woodrow, W., New York, N. Y.
Yamada, F. T., E. Pittsburgh, Pa.
Yamamoto, S. T., Pittsburgh, Pa.
Young, R. L., New York, N. Y.
Yunginger, G. S., New York, N. Y.
Total 182

Foreign Applications

Arnar, O. B., Reykjavik, Iceland
Davis, G. C., Rancagua, Chile, S. A.
Harada, K., Kobe, Japan
Henderson, G., Edinburgh, Scotland
Jacob, Arthur, (Member), London, E. C., England.
Nagasaki, T., Kobe, Japan
Nakarawa, P., Kobe, Japan
Nakashima, S., Kobe, Japan
Noble, K. J., Rugby, England.
Russell F. G., Bombay, India
Stephenson, E. J., (Member), London, England.
Terada, M., Kobe, Japan
Urie, R. J., Tucuman, Argentine Rep., S. A.
Total 13

STUDENTS ENROLLED JANUARY 10, 1919

9761	White, B.L., Casino Tech. School
9762	Goss, H. R., Univ. of Minn.
9763	Manderfeld, E. C., Univ. of Minn.
9764	Podosin, J., Univ. of Minn.
9765	Nelson, G. A., Univ of Minn.
9766	VanHarrington, M., Univ. of Minn.
9767	Silkensen, L. L., Univ. of Minn.
9768	Peterson, R. M., Univ. of Minn.
9769	Petrich, A. C., Univ. of Minn.
9770	Janzen, W. H., Univ. of Minn.
9771	Hough, W. E., School of Engg. of Milwaukee
9772	West, R. D., School of Engg. of Milwaukee
9773	Csisek, J. J., The Drexel Inst.
9774	Culver, L. R., The Drexel Inst.
9775	Mills, P. J., The Drexel Inst.
9776	Ratcliffe, E. E., The Drexel Inst.
9777	Ross, J. J., The Drexel Inst.
9778	Wright, S. J., The Drexel Inst.
9779	Buss, R. S., Lehigh Univ.
9780	Roche, G. J., Lehigh Univ.
9781	Macarow, F. G., Lehigh Univ.
9782	Smoyer, L. M., Lehigh Univ.
9783	Nevins, B. R., Lehigh Univ.
9784	Townsend, S. C., Lehigh Univ.
9785	Wick, A. J., Lehigh Univ.

9786 Wildman, G. A., Lehigh Univ.
9787 Eisenberg, B. N., Lehigh Univ.
9788 Herman, J., Lehigh Univ.
9789 Newell, N. A., Lehigh Univ.
9790 Wiegner, W. K., Lehigh Univ.
9791 Osholenk, S., Lehigh Univ.
9792 Siegfried, J. A., Lehigh Univ.
9793 George, D. M., Lehigh Univ.
9794 Armstrong, M. S., Lehigh Univ.
9795 Dubson, J. F., The Drexel Inst.
9796 Dutton, T. D., The Drexel Inst.
9797 Hartmann, F. J., Jr., The Drexel Inst.
9798 Kurlander, J. H., The Drexel Inst.
9799 Peoples, R. E., The Drexel Inst.
9800 Stryker, N. R., The Drexel Inst.
9801 Williard, J. A., The Drexel Inst.
9802 Fronik, A., Brooklyn Poly. Inst.
9803 Keiser, M., Brooklyn Poly. Inst.
9804 Seeley, R. E., Brooklyn Poly. Inst.
9805 Feman, H., Brooklyn Poly. Inst.
9806 Heisler, S. D., Brooklyn Poly. Inst.
9807 Doppel, G. F., Brooklyn Poly. Inst.
9808 Estabrook, H. E., Brooklyn Poly. Inst.
9809 Goodale, J. E., Brooklyn Poly. Inst.
9810 Anderson, A. E., Rensselaer Poly Inst.
9811 Burdick, W. T., Rensselaer Poly. Inst.
9812 Bennett, R. S., Rensselaer Poly. Inst.
9813 Emery, E. V., Purdue Univ.
9814 Lang, G. M., Delaware Coll.
9815 Ryan, P., Cornell Univ.
9816 Skinner, R. G., Cornell Univ.
9817 Clarke, W. H., Cornell Univ.
9818 Curtis, G. G., Cornell Univ.
9819 Duskis, E., Cooper Union
9820 Keiley, J. D., Brooklyn Poly Inst.
9821 Rose, B., Brooklyn Poly. Inst.
9822 Tyjewski, M. S., N. Y. Electrical School
9823 Van Sweringen, R. A., Cornell Univ.
9824 Dodson, J. L., The Drexel Inst.
9825 Halperin, H., Cornell Univ.
9826 Cogan, Rensselaer Poly. Inst.
9827 Carranza, J., Rensselaer Poly. Inst.
9828 Dillaway, H. B., Rensselaer Poly. Inst.
9829 O'Brien, J. M., Rensselaer Poly. Inst.
9830 Brennan, H. B., Rensselaer Poly. Inst.
9831 Shih, A. T., Rensselaer Poly. Inst.
9832 Hilfrank, W. L., Rensselaer Poly. Inst.
9833 Dowell, C. P., Univ. of Ill.
9834 Schilling, E. W., Univ. of Ill.
9835 Loomis, A. J., Univ. of Wash.
9836 Barker, T. H., 2nd., Univ. of Penn
9837 Lange, H. T., Washington Univ.
9838 Levin, N., Brooklyn Poly. Inst.

Total 78

ADDRESSES WANTED

Any reader knowing the present address of any of the following members is requested to communicate with the Secretary at 33 West 39th Street.

Edward de A. Braga
(former address)
2-4 Stone St.,
New York, N. Y.

Howard K. Cook
(former address)
Counties Gas & Elec. Co.
Norristown, Pa.

F. C. Dieterich
(former address)
17 Watertown Ave.
Waterbury, Conn.

Nils Erricksson
(former address)
198 Beverly St.
Toronto, Canada.

A. Guerra
(former address)
Mexican Light and Power Co.
Mexico City, Mex.

Samuel K. Lessey
(former address)
510 So. 47th St.
Philadelphia, Pa.

H. S. Logan
(former address)
214 15th Ave.
Seattle, Wash.

Percival Moore
(former address)
Pendennis Club
Louisville, Ky.

B. Neel
(former address)
Floral Park
Wilkinsburg, Pa.

Louis F. Nosek
(former address)
2245 E. 82nd St.
Cleveland, Ohio

PERSONAL

Paul Cloke has been elected to a Professorship of Electrical Engineering at the University of Arizona, Tucson, Arizona.

Mortimer Freund, who has been in charge of the Trench Warfare Branch, Loading Section of the Explosives and Loading Division, Ordnance Department at Washington, D. C., has resigned from that service and has resumed his activities in the firm of Eadie, Freund and Campbell, consulting mechanical and electrical engineers, New York City.

Professor A. E. Kennelly, Past President, of Harvard University and the Massachusetts Institute of Technology, has been elected recently an Honorary Member of the Institution of Electrical Engineers in London.

Harold G. Payne having completed recent government appointments is now available for engagements as electrical engineer on problems in connection with design of power plants and systems, industrial electric power and lighting layouts, reports on utility properties, valuations and rate adjustments, management and operation. Offices at 201 Chamber of Commerce, Boston, Mass.

Frank P. Fahy has been recently awarded the John Scott Legacy Medal and Premium by the City of Philadelphia, acting on the recommendation of the Franklin Institute, for his work in connection with the development of the Fahy Permeameter. With this instrument accurate measurements of the characteristics of materials can be made with ease, and it is so constructed that long specimens of bar, rod and sheet material may be tested at any point of their length.

N. M. Haralson who has been connected with the Bureau of Aircraft Production since September 1917, and who has been Chief of the Instrument Department of the New York office since June 1918 has resigned his position and after February 15th will be connected with the Haralson Sales Company, Inc., 752 Brown Marx Bldg., Birmingham, Ala., in the capacity of Sales Engineer.

Charles R. Underhill, until recently Captain in the Air Service, Aeronautics, received his discharge from the army on January 8th and has returned to New Haven in the capacity of Chief Electrical Engineer for the Acme Wire Co. For sometime Capt. Underhill was in charge of tests in flight for the Radio Development Section of the Signal Corps at Langley Field, and when this work started at Little Silver he was transferred to the School for Aerial Observers at Langley Field, where he organized the Radio Department and the Simulative Artillery System. Later Capt. Underhill was transferred to the Division of Military Aeronautics, Washington, D. C where he specified the radio equipment for Air Service Operations.

Fredk. A. Scheffler formerly with the Babcock & Wilcox Co., New

York has become associated with the Fuller Engineering Company of Allentown, Pa. Mr Scheffler is manager of the Department devoted to the application and introduction of pulverized coal equipment for steam power plants. His address will be Fuller Engineering Company, 50 Church St., New York City.

CAPTAIN EDWARD E. ASHLEY, JR., for many years Consulting Mechanical and Electrical Engineer for Starrett & Van Vleck, Architects, New York City, has resigned his commission in the Air Service of the U. S. Army, to accept appointment as Sales Engineer of the Mercury Mfg. Co., Chicago, Illinois. This company manufactures electrically driven tractors for use in connection with industrial haulage systems.

DONALD MC NICOL, who during the past ten years has been assistant electrical engineer of the Postal Telegraph Cable Company, New York, has become managing editor of *Telegraph and Telephone Age.* Mr. Mc Nicol is a Fellow of the Institute and is chairman of the committee on Telegraphy and Telephony.

OBITUARY

PROFESSOR R. C. CARPENTER of Cornell University died at his home in Ithaca on January 19. He was born in 1852 and graduated from Michigan University in 1877, and served for one year as assistant engineer of construction of the Detroit and Bay City R. R. He then became professor at Michigan Agricultural College and was in charge of the department of mathematics and civil engineering from 1878 to 1890 when he accepted the associate professorship of experimental engineering at Sibley College, Cornell. Prof. Carpenter also conducted a consulting engineering practise of considerable magnitude.

ROSSITER W. RAYMOND, Ph. D., LL. D., mining engineer, metallurgist, lawyer and author died on December 31, 1918. He was born in Cincinnati, Ohio, April 27, 1840 and received his early education in the schools of Syracuse. He graduated from the Brooklyn Polytechnic Institute in 1858 and spent the next three years at universities in Germany. Returning to the United States in August, 1861, he entered the Federal Army and was later commended for gallant conduct. From 1864 to 1868 he practised as a consulting mining engineer and metallurgist and in the latter year was appointed U. S. Commissioner of Mining Statistics which position he held until 1876. From 1870 to 1882 he lectured on economic geology at Lafayette College. From 1875 to 1895 he was associated as consulting engineer, for prominent firms in the iron, steel and coal business. From 1885 to 1889 he was New York State Commissioner of Electric Subways for Brooklyn and in 1889 became consulting engineer for the New York and New Jersey Telephone Company. Dr. Raymond was admitted to the bar in 1898 and was connected with many cases involving mining and patent law, and in 1903 became lecturer on Mining Law at Columbia. He was an original member of the American Institute of Mining Engineers, vice-president in 1871, 1876 and 1877, president from 1872 to 1875, secretary from 1884 to 1911, and Secretary Emeritus from 1911 until his death. Dr. Raymond was a member of the American Philosophical Society, an honorary member of the Society of Civil Engineers of France, the Iron and Steel Institute and the Institute of Mining and Metallurgy of Gt. Britain besides various other technical organizations. Dr. Raymond was a most prolific and interesting writer on a wide variety of subjects and an orator of great ability.

AN APPEAL

To the Membership of the Institute.

The Employment Bureau of the A. I. E. E. cooperating with the Engineering Societies Employment Bureau, as recently established under the Board of Management consisting of the Secretaries of the A. S. C.E., the A. I. M. E., the A. S. M. E. and the A. I. E. E. is feeling the heavy and daily growing demand for employment existing among the "Engineers". Men from the army, the navy, former civilian government employees and many others come to us for aid. They are of all types and grades from the clerk to the highly trained engineer executive.

We therefore urge you, if vacancies exist in your organization or if you come in contact with others seeking technically trained men, to speedily inform us of such opportunities giving the necessary qualifications for each position, that is, experience required, salary, location, etc. Such information will be brought to the attention of properly qualified men on our available files and will often lead to the prompt filling of the vacancy. If you so desire, announcements of vacancies may be published without charge in the monthly PROCEEDINGS.

Put us in touch with such information on opportunities as you may have and you will be aiding greatly in the readjustment of the labor situation in the engineering field.

Very truly yours,
F. L. HUTCHINSON
Secretary.

ENGINEERING SERVICE BULLETIN

Opportunities.—The Institute, as stated in the letter above, is particularly anxious to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in the BULLETIN. The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Services Available.—Under this heading brief announcements (not more than fifty words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office reference files.

Note.—Copy for publication in the BULLETIN should reach the Secretary's office not later than the 20th of the month if publication in the following issue is desired. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

OPPORTUNITIES FOR SERVICE

V-468. Wanted: Night supervisor for 30,000 Kw. turbine plant located in Southern New England. Requires man experienced along this line and with clean past record. Salary $2500. at start.

V-469. Man with practical experience in testing electrical motors and generators, not necessarily a technical man, but practical experience insisted on. Want a man experienced enough so that he can go into our shops and start immediately turning out motors and generators. Salary $130. to $140. per month.

V-470. Light and power company in Iowa, 50,000 Kw. plant, wants young technical man for boiler and turbine testing, efficiency determinations, etc. Must have had some practical experience along such lines. Salary $1800. to start. Good opportunity for advancement.

V-471. Mather & Platt Ltd., Park Works, Manchester, England, manufacturers of mechanical, textile, hydraulic and electrical plant, require a chief research engineer of British descent, to organize and take full charge of a works research department and laboratory. The highest qualifications and wide knowledge of such work are essential. Apply by letter with full details, stating how soon at liberty, to the above address.

V-472. Power company in Nebraska requires services of young engineer experienced in underground cables and structure. Alternating current. Salary to start about $115. per month. Give age, experience and references.

V-473. Wanted by electrical engineering journal, electrical or mechani graduate for assistant technical editor and aid to circulation manager. Should be familiar with cut making, have writing ability and be of good address. Opportunity to grow into good permanent position. Give age, experience and salary.

V-474. Electrical engineer wanted by firm manufacturing distribution specialties, for position of chief draftsman, designing and some shop supervision. Practical knowledge of distribution and technical education essential. Location Chicago. Salary $2000. to $2600.

V-475. Salesman, experienced in handling technical equipment. Should have a general knowledge of electricity and of manufacturing procedure. Moderate salary to start.

V-476. Wanted division superintendent of light and power company. Location Porto Rico. Applicant must be in thirties, have had thorough technical and practical training in central station business, energetic, optimistic and able to handle all grades of labor. He will supervise distribution, operation, maintenance, inspection, new business, contracts, investigation and design. Good opportunity for man who can take hold, reconstruct and develop. Excellent climate and living facilities. Give complete record, stating length of each employment. Furnish photo, references and salary expected.

V-477. Wanted engineer to take charge of steam plant and substations of light and power company in Porto Rico. Must have had good technical training, both electrical and mechanical and be experienced in handling men. Able to design or stand watch when necessary. He will be in charge of steam plant, substations, repair shop, meter dept., concrete pole manufacture, hydroelectric design, construction and operation. Excellent climate and living facilities. Give experience in detail age, references and salary expected.

V-478. Power and railway corporation, central New York, wants man experienced in electrical end of power house work. Salary approximately $100. per month.

V-479. We need a man who is familiar with switchboards, circuit breakers, and meters, who knows how to write. Technical graduate preferred.

V-480. Young engineer with some sales experience wanted, with knowledge of large steam and water valves and their application. Some knowledge of direct and alternating current motors essential.

V-481. Large firm, location France, wants electrical engineer thoroughly familiar with design of very high voltage transformers and equipment. Good position guaranteed to A-1 competent man. Give detailed experience, age and salary expected.

V-482. Large telephone company in Bell System operating in central and northern central states requires a number of men experienced in telephone inventory and valuation work. Has in view at present from one to three years of extensive work and can offer permanent positions to a limited number of men who prove themselves capable. Salaries $1500. to $1800. per annum, depending upon experience and ability, with opportunity for advancement.

V-483. Wanted: Technical graduate in electrical engineering. At least five years experience in the manufacturing of detail electrical apparatus. Salary about $200. per month. Location Pennsylvania.

SERVICES AVAILABLE

1129. Technical graduate with 22 months of G. E. testing experience, combined with additional engineering practice, desires to locate with an electric manufacturing company.

1130. At present on active duty in U. S. N. but expect to be released within the next few weeks. Desire a position preferably in sales department of electrical manufacturing company. Graduate electrical engineer. Have had some engineering experience, electrical and mechanical, and extensive experience in motor, dynamo and welder testing and repairing.

1131. Chemical and electrical engineer, age 26, graduate of Massachusetts Institute of Technology, returning from overseas, desires position, preferably with company employing electric power in chemical processes. Address Thos. C. Atchison, 45 Hillside Avenue, Lawrence, Mass.

1132. Electrical engineer, several years' experience as superintendent of equipment for a large electric railway system. Also capable of designing electrical machinery and making power house layouts. Production engineer. Can deal successfully with labor and secure efficient results. Thirty-eight years old. Married.

1133. Electrical engineer with strong technical qualifications (especially in alternating currents) and considerable executive ability, desires change of position. Would especially consider electrical testing organization offering responsible position with opportunities for new work or power and distribution. Experience in laboratories (testing and research), central station and distribution, railway and some industrial power. Salary neighborhood of $4000.

1134. Technical graduate, electrical, 26 years old, married. Two and one-half years' experience miscellaneous electrical, equipment as motors, generators, rectifiers and batteries.

1135. Electrical engineer, American, college education, married, age 32, fourteen years' experience, including six years in shops, desires position as electrical engineer, chief draftsman or chief electrician. Experienced in machinery, power, switchboard and lighting installations, their maintenance and repair. Six years with present employers. Salary $2400.

1136. Chief draftsman and designer, age 38, nine years sub and central station; eight years factory experience drafting, design, construction, research. Good organizer, producing results at minimum cost, trained for position from layoutman and designer to manager and engineer. Salary according to responsibility and local circumstances. Location New York, Brooklyn, Newark, New Jersey.

1137. Technical graduate 1916, age 28, wishes to locate with a light and power company as meter engineer. Two years with a large electrical manufacturing concern on test floor on latest type of measuring instruments. Available on short notice. Salary $1800.

1138. Commercial engineering, sales management. Will be free for engagement in early spring. At present Captain Ordnance U. S. Army. Graduate Cornell '09, degree M. E. Ten years with electrical manufacturer. Member A. I. E. E. Age 33. Salary $4000.

1139. Superintendent with fifteen years' experience in the construction and operation of large power developments and now with a large power company, desires to make change. Thoroughly experienced in central station, transmission and distribution. Would consider proposition with industrial company.

1140. Mechanical-hydraulic engineer, at present employed as chief draftsman important hydroelectric development, desires change. Fifteen years' experience draftsman, designer, chief draftsman, designing engineer and chief engineer in hydroelectric and industrial engineering. Would locate South or West or go abroad. Available in one month. Minimum salary $3000.

1141. Electrical engineer, age 30, year and half in ordnance work, assistant metallurgist and superintendent of electrical heat treating department. Experienced in design and estimating of power distribution. Inspector transmission line equipment. Twenty-six months G. E. test. Will consider engineering, manufacturing or sales in or near New York City.

1142. First Lieutenant Ordnance U. S. Army wants position as manager, new business department electric light and power company. Graduate Georgia Tech. E. E. 1909. A. I. E. E. Nine years engineering and sales experience. Thoroughly familiar with industrial power requirements, competent to get and hold business. Will be available March 1. Minimum salary $3,600.

1143. Electrical engineer, competent designer of direct and alternating current motors, generators and accessories with extended and valuable business experience in the up-to-date manufacture of same. At present in responsible position. Desirous of becoming associated with established manufacture, requiring man of executive ability who may acquire interest.

1144. Electrical engineer, graduate University of Illinois 1915, mechanical engineering experience in factory, production and plant design.

1145. Army Captain, electrical engineer, 37, college graduate, fourteen years' experience from electrician to position of large responsibility. Design, installation and operation of power plants, substations, distribution systems and industrial motor equipments, 1000 to 50,000 kva. Several years abroad. Now in charge of camp utilities after completing installation of same. Available in April.

1146. Chief electrician. Experienced on A-C. or D-C. work, industrial or power plant layout and maintenance work. Thoroughly acquainted with economical operation of storage batteries. Age 35. Married.

1147. Electrical engineer, graduate '14, Associate A. I. E. E., twelve years' experience; specialized in the installation and maintenance of oil engines, electric power and pumping station; have wide experience in designing special plants, specifications, estimates and mathematical calculations; can handle men. Will be available February 1. Age 33. Married.

1148. Electrical engineer, age 31, married, British nationality, technical graduate, eleven years' experience in U. S. A. and Canada on sales, construction and operation of hydroelectric equipment, also the industrial application of motors. Now manager in Canada for large European electrical manufacturing company. Present salary $3600. Will go to any healthy location.

1149. Electrical trained executive, now connected with the Bureau of Aircraft Production having business relations with many Government contractors, wishes to connect with an electrical manufacturer in a sales capacity. Good references, strong personality. Associate A. I. E. E., member Engineers Club of Philadelphia. Age 27. Married.

1150. Electrical engineer, age 32, married, desires position with light and power company as superintendent or assistant. College graduate. Over two years with General Electric Co. in testing department and in field locating power equipment trouble. Four years in electrical engineering department of large street railway company. Salary $1800-$2000.

1151. Have your business represented in Washington, Baltimore, and surrounding territory on a commission basis by an electrical-mechanical engineer. Age 28. Married. Associate A. I. E. E. Technical graduate with specialized experience in design, construction and operation of generating stations, substations and high tension transmission lines. Will handle exclusive agency only.

1152. Electrical and mechanical engineer, technical graduate, Member A. I. E. E., age 32, single, over ten years in design and construction of steam and hydroelectric power plants, transmission lines and substations. Until recently held commission in Ordnance Department, Engineering Division. Applicant desires location in executive position with growing concern, preferably in or near New York City.

1153. Technical graduate electrical engineer, Associate A. I. E. E., desires position where executive ability and tact is required. Eight years experience as consulting engineer and contractor in illuminating engineering, power distribution and control, both interior and exterior installations. Until recently with War Department, Washington, D. C., as consulting engineer on illumination, Available February 1.

1154. Electrical engineer, graduate, married, twenty years varied experience in design and construction, mill power and lighting, steam and hydroelectric power and sub-stations, transmission lines, distribution, shipyards, etc., valuation work. Good executive. Good references.

1155. Electrical engineer, graduate E.E., Member A. I. E. E., age 32, married desires a position as Associate Professor of E.E., or a responsible position in a research department. Nine years' experience as a professor of electrical engineering and as a consulting electrical engineer. Now Lieutenant in U. S. N. R. F. on active duty, for engineering duties only. Will be discharged after February 1 on application. References, former associates and employers.

1156. Technical graduate, age 37. Twenty years electrical experience construction, maintenance, designing, drafting, sale. Was employed eight years as chief electrician by large shipbuilding company in Denmark; eight months electrical designing in connection with ships for the Emergency Fleet Corp. Will go anywhere in U. S. A., Canada, Japan, China.

1157. Electrical graduate, 1903, member A. I. E. E., fourteen years' experience electrical and mechanical engineering, some civil engineering and construction work, with large manufacturing and power companies; principal experience hydroelectric plant and transmission design, age 38, married; excellent health, industrious and responsible; desires permanent position in Arizona or New Mexico. Minimum salary $2400.

1158. Lieutenant of Field Artillery with a master degree in electrical engineering, G. E. Test course and four years' experience as inspector of electrical machinery and materials, desires a permanent position with power company or industrial plant where this experience will be most valuable. Best of references. Age 28. Salary $175.

1159. Member A. I. E. E., twenty years' experience, electric light and power construction, operation, maintenance, stations, meters, relays. Thirteen years with one company as superintendent meters, chief electrician, electrical engineer. At present power specialist, industrial plants. Married, age 41. Salary $2500.

1160. Electrical engineer, technical graduate, wide experience in layouts and construction of industrial installations and power plants.

1161. Industrial Engineer. Now works engineer in a plant of 6,000 men. Experienced in the design of special industrial equipment and special machine tools. Specialized experience on A-C. and D-C. motors, automatic machine tool control and production records and schedules. Experienced in handling men. Salary $4000. Technical graduate. Age 32. Married.

1162. Electrical engineer, 34, having fourteen years broad electrical and mechanical experience with large industrial, railways, power and lighting companies, desires executive position of responsibility with established and reliable industrial or public utilities company. Construction or operation. Salary $4200.

1163. Backfrom France, Lieutenant, Corps of Engineers, offers his personal services. Electrical engineer, graduate of Massachusetts Institute of Technology, twenty-eight years of age. Experienced in steam-electric power plant design, construction and operation. $2500.

1164. Young technical man, 30, at present instructing in large eastern institution on electrical machinery, desires to connect permanently with electrical concern in South, far West, or, preferably, Alaska. Possibility of expansion main consideration. Present remuneration $2400.

1165. Electrical engineer, degree M.E., married. One year G. E. machine work; eight years central station testing, construction, installation; one year power and lighting layout. Some experience purchasing supplies. Desires position with industrial plant or central station.

1166. Ensign U. S. Naval Aviation, just released from active duty. Married. Age 27. Two years testing and three years engineering and manufacturing experience in transformer and motor design with the G. E. Co., five months power-house construction experience with Stone & Webster.

ACCESSIONS TO THE ENGINEERING SOCIETIES LIBRARY

(From December 1, 1919, to December 31, 1919)

Unless otherwise specified, books in this list have been presented by the publishers. The Societies do not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

THE A-B-C OF AVIATION.

A complete, practical Treatise outlining clearly the Elements of Aeronautical Engineering with special Reference to simplified Explanations of the Theory of Flight, Aerodynamics and Basic Principles underlying the Action of Balloons and Airplanes of all Types. A non-technical Manual for all Students of Aircraft. This Book includes Instructions for lining up and inspecting typical Airplanes before flight and also gives easily understood Rules for flying. By Victor W. Pagé. N. Y., The Norman W. Henley Publishing Co., 1918. 11 + 274 pp., 128 illus., 7 pl., 9x6 in., cloth, $2.50.

A companion volume to the author's "Aviation Engines", giving a simple account of the operation and repair of airplanes. Intended for use by prospective aviators and mechanics, not as a treatise for engineers and designers.

AEROBATICS.

By H. Barber. N. Y., Robert M. McBride and Co., 1918. 61 pp., 29 pl., 11 x 18 in., cloth, $3.

This book is an explanation of the general rules governing flying. The instruction is arranged in progressive form and is intended to convert the novice into an expert pilot in the shortest possible time, with the greatest possible degree of safety to himself and his machine.

AMERICAN ENGINEERS BEHIND THE BATTLE LINES IN FRANCE.

By Robert K. Tomlin, Jr. 1st edition. N. Y., published by Engineering News-Record. (McGraw-Hill Book Co., Inc., sole selling agents.) 1918. 91 pp., illus., 12 x 9 in., ¼ cloth, $2. (Gift from McGraw-Hill Book Co.)

These nineteen articles, reprinted from the McGraw-Hill periodicals of they ear, described various phases of the engineering work executed by the American Army. Gathered together, they form an interesting account of the problems and the methods used to solve them.

AMERICAN PROBLEMS OF RECONSTRUCTION.

A National Symposium on the Economic and Financial Aspects. Edited by Elisha M. Friedman, with a foreword by Franklin K. Lane. N. Y., E. P. Dutton and Co., 1918. 23 + 471 pp., 8 x 5 in., cloth, $5.

CONTENTS: Part I. A Perspective of the Question. Part II. Efficiency in Production. Part III. Adjustments in Trade and Finance. Part IV. Programs, Monetary and Fiscal.

The editor here presents the opinions of some twenty-eight prominent Americans, in the hope of stimulating thought on the subject. The specific points treated are the temporary effects of the war, the best methods of facilitating our readjustment to peace conditions, the permanent effects of the war, the changes that these will effect in our national life, and the national economic policy that should be adopted.

ANNUAL CHEMICAL DIRECTORY OF THE UNITED STATES.

2d Edition, 1918. Consulting Editor, B. F. Lovelace; Managing Editor, Charles C. Thomas. Baltimore, Williams and Wilkins Co., (copyright 1918) 534 pp., 9 x 6 in., cloth, $5.

This directory is intended as a comprehensive review of all matters relating to industrial, technical and scientific chemical development in the United States. It contains lists, classified by subject and location, of manufacturers and dealers in chemicals and allied products and in equipment; a geographical directory of industrial, institutional, federal, state, municipal and commercial laboratories; a list of technical and scientific societies of the world, and bibliographies of technical and scientific journals, and of the important new books of 1917-1918. A "News and Notes" section completes the work. This second issue is approximately twice as large as the first.

THE ATOMIC WEIGHTS OF BORON AND FLUORINE.

By Edgar F. Smith and Walter K. Van Haagen. Wash., Carnegie Institution, 1918. 65 pp., 4 illus., 4 tab., 10 x 7 in., paper, $1.

The authors describe in detail their work upon the atomic weight of boron and give a recalculation of that of fluorine, based upon their new value for boron. This latter value is considerably lower than that hitherto accepted.

ELECTRIC MOTORS AND CONTROL SYSTEMS.

A Treatise on Electric Traction Motors and their Control. By A. T. Dover. Lond., Sir Isaac Pitman and Sons, Ltd., 1918. 16 + 372 pp., 315 illus., 9 tab., 9 x 6 in., cloth, $6.

In this volume, which is an amplification of a portion of his work on "Electric Traction", the author treats of the application of electric motors to railways. The endeavor has been to meet the needs of engineers and advanced students of engineering, rather than those of specialists in elelctric railway equipment.

ELECTRICAL EQUIPMENT OF THE MOTOR CAR.

By David Penn Moreton and Darwin S. Hatch. N. Y., U. P. C. Book Co., Inc., 1918. 506 pp., 428 illus., 7 x 5 in., flexible cloth, $2.50.

This work is intended to give the lay reader sufficient knowledge of the electrical equipment of an automobile to enable him to operate it intelligently, and to make ordinary adjustments and repairs. It is compiled from a series of articles that appeared in Motor Age, with additions and emendations.

ELECTRICITY AND MAGNETISM FOR ENGINEERS.

Part I. Electrical and Magnetic Circuits. By Harold Pender. 1st Edition. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1918. 11 + 380 pp., 98 illus., 9 x 6 in., cloth, $3.

This volume covers substantially the same ground as that of the author's "Principles of Electrical Engineering." The method of treatment, however, is distinctly different. The various laws and relations are more fully discussed and a greater number of practical applications are given. Particular emphasis is laid upon exact quantitative statements of the fundamental laws.

GRAPHIC CHARTS FOR THE BUSINESS MAN.

By Stephen Gilman. Chic., La Salle Extension University, 1918, 62 pp., 56 illus., 9 x 6 in., paper.

A pamphlet showing the value of charts in presenting statistical data, and describing some of the varieties used in business.

HENDRICK'S COMMERCIAL REGISTER OF THE UNITED STATES FOR BUYERS AND SELLERS.

With which has been incorporated "The Assistant Buyer." Especially devoted to the Interests of the Electrical, Engineering, Hardware, Iron, Mechanical, Mill, Mining, Quarrying, Chemical, Railroad, Steel, Architectural Contracting and kindred Industries. A complete and reliable annual Register of Producers, Manufacturers, Dealers and Consumers connected with the aforesaid Industries. N. Y., S. E. Hendricks Co., Inc., (copyright 1918) 2381 pp., 10 x 8 in., cloth, $10.

This register of producers, manufacturers, dealers and consumers connected with the engineering and industrial activities of the country has been carefully revised and corrected. The firms included are listed alphabetically and also carefully classified. A section containing trade names and brands, with the names of manufacturers, forming a convenient ready reference list for purchasers, is a distinctive feature.

LOCOMOTIVE HAND-BOOK.

Compiled by American Locomotive Company. N. Y., 1917. 195 pp., 9 illus., 89 tab., 6 x 4 in., leather, 75 cents.

The compilers have arranged the tables, formulas and other information used by locomotive designers, in a convenient book of pocket size.

MILL AND CYANIDE HANDBOOK.

Comprising Tables, Formulas, Flow-sheets, and Report Forms, compiled and arranged for the use of Metallurgists, Mill-men and Cyanide Operators. By W. A. Allen. Lond., Charles Griffin and Co., Ltd.; Phila., J. B. Lippincott Co., 1918. 10 + 128 pp., 7 x 4 in., cloth, $2. (Gift from J. B. Lippincott Co.)

The author has tabulated the physical, chemical and mechanical data needed by mill-men, in volume of convenient size, well-indexed. A glossary of mill and cyanide terms is included.

MODERN SHIPBUILDING TERMS DEFINED AND ILLUSTRATED.

Including a Series of Photographs showing the Progressive Steps of Construction, together with an Appendix on Electric Welding. By F. Forrest Pease. Phila. and Lond., J. B. Lippincott Co., (copyright 1918). 143 pp., 68 pl., 8 x 5 in., cloth, $2.

This work contains a glossary of the more common words and phrases used in building a steel ship; a list of shipyard trades and the duties performed by each; a series of instruction charts on electric welding; a list of symbols used on plans and parts; a description of the Isherwood system of shipbuilding; directions for the use of acetylene, hydrogen and oxygen for cutting and welding; and a select list of books on ship construction and equipment. The plates illustrate the construction of a ship by the usual methods, the construction of the "fabricated" ship, and the tools, machines and installations.

OXWELDING AND CUTTING.

Manual of Instruction. (Compiled by the Oxweld Acetylene Company, Jersey City, N. J. 1st edition, (copyright 1918) 124 pp., illus., 8 x 5 in., paper.

The manual describes the apparatus, the methods of using it and gives a series of practice problems illustrating correct methods of meeting those that occur in shops where oxy-acetylene is used for cutting and welding.

PRACTICAL AVIATION.

An Understandable Presentation of Interesting and Essential Facts in Aeronautical Science. By Charles B. Hayward, 2nd edition. Chic., American Technical Society, 1919. 784 pp., illus., 8 x 6 in., flexible cloth, $3.75.

This volume treats of the theory, design and construction of airplanes and dirigible balloons, and their motors; and describes the types in use. Considerable space is given to the military uses of airplanes and to the methods of flying used by military aviators.

PRACTICAL AVIATION FOR MILITARY AIRMEN.

By Major J. Andrew White. N. Y., Wireless Press, (copyright 1918) 197 pp., illus., pl., 9 x 6 in., cloth, $1.75.

The author's aim has been to produce a text-book suited for intensive study by students of military aviation who wish to learn the essentials of flying in the shortest possible time. The reading matter has been condensed by eliminating everything but essentials, and providing a large number of drawings, conveniently arranged.

SCRAP METALS.

Study of Iron and Steel Old Material, Its Preparation and Markets. By George H. Manlove. The Old Metals, by Charles Vickers. Cleveland, The Penton Publishing Co., 1918. 278 pp., 8 x 6 in., cloth, $2.

The two monographs which compose this volume treat of the utilization of old metal. The first is restricted to scrap iron and steel, while the second discussed non-ferrous metals. The book is a pioneer attempt to present the scrap industry in print.

SIMPLIFIED NAVIGATION FOR SHIPS AND AIRCRAFT.

A Text Book based upon the Saint Hilaire Method. By Charles Lane Poor. N. Y., The Century Co., 1918. 17 + 126 pp., 10 illus., 7 charts, 4 tab., cloth, $1.50

This work is an attempt to explain in non-technical language and without the use of complicated mathematics the principles which form the basis of modern methods of navigation. Particular attention is given to aerial navigation.

A STUDY OF ENGINEERING EDUCATION.

Prepared for the Joint Committee on Engineering Education of the National Engineering Societies. By Charles Riborg Mann. (Carnegie Foundation for the Advancement of Teaching, Bulletin number 11.) N. Y., 1918. 11 + 139 pp., 10 x 8 in., paper.

The purpose of this report is to examine the fundamental question of the right methods of teaching and of the preparation of young men for the engineering professions. In the light of the fifty years of experience of the engineering colleges of the United States, an effort has been made to suggest the pedagogic basis of the course of study intended to prepare young men for the work demanded of the engineer to-day, without losing sight of the piont of view of the teacher, the engineer, the manufacturer and the employer. A limited number of typical schools were visited and studied by Professor Mann and the views of the whole engineering profession throughout the country were ascertained in the course of the investigation. It is the hope of the Committee that the report will awaken wide interest because of its applicability, and that its influence on engineering education will be beneficial.

SUCCESS IN THE SMALL SHOP.

By John H. Van Deventer. 2d edition. N. Y., published by American Machinist, (McGraw-Hill Book Co., Inc. sole selling agents) 1918. 137 pp., illus., 11 x 9 in., ¼ cloth, $1.75.

A series of articles, fifty in number, dealing with the problems of small machine shops, that appeared originally in the American Machinist. The articles discuss economic conditions, management, equipment, methods, etc., and are intended to be of practical help to owners and workmen.

TOPOGRAPHIC STADIA SURVEYING.

A Manual with Reduction Tables and a new Type of Reduction Diagram. By C. E. Grunsky. N. Y., D. Van Nostrand Co., 1917. 99 pp., 18 illus., 8 tab., folding diag. in cover pocket, 7 x 4 in., cloth, $2. (Gift from author.)

The author describes a method of surveying and a special type of diagram for the reduction of stadia notes, which has been found to be very satisfactory in practice.

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*A complete list of the officers, committees and representatives of the Institute will be found in the January, 1919, issue of the Proceedings.

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*Inactive at present, due to the war.

PROCEEDINGS
OF THE
American Institute of Electrical Engineers

Vol. XXXVIII
Number 3

MARCH, 1919

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TABLE OF CONTENTS

Section I.—Institute Affairs

March Institute Meeting in Boston 85
Future A. I. E. E. Meetings 86
Future Section Meetings 86
Plans of A. I. E. E. Committee on Development 86
A. I. E. E. Midwinter Convention 91
Joint Meeting in India 92
Delegates to France Report to Societies 94
Institute of Radio Engineers 100
Dismissal of Public Service Commission Engineers in New York City 100
Past Section Meetings 101
Past Branch Meetings 103
Associates Elected February 19, 1919 104
Associates Re-elected February 19, 1919 111
Members Elected February 19, 1919 111
Transferred to Grade of Fellow, February 19, 1919 112
Transferred to Grade of Member, February 19, 1919 112
Recommended for Transfer 112
Application for Election 112
Students Enrolled February 19, 1919 115
Addresses Wanted 117
Personal 118
Engineering Service Bulletin 119
Accessions to Engineering Societies Library 123

Section II.—Papers and Reports

The General Equations of the Electric Circuits III. By Charles P. Steinmetz, New York, February 20, 1919 249
Fusion in Arc Welding. By O. H. Eschholz, New York, February 21, 1919 319
Welding as a Process in Ship Construction. By S. V. Goodall, New York, February 19, 1919 329
Radio Telephony. By E. B. Craft and E. H. Colpitts, New York, February 21, 1919 337
Telephone Circuits with Zero Mutual Induction. By William W. Crawford, New York, February 21, 1919 377
Theory of the Transient Oscillations of Electrical Net works and Transmission Systems. By John R. Carson, New York, February 21, 1919 407

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GEORGE R. METCALFE, Editor.

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American Institute of Electrical Engineers

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PROCEEDINGS

Vol. XXXVIII MARCH, 1919 Number 3

MARCH INSTITUTE MEETING IN BOSTON

The 348th meeting of the American Institute of Electrical Engineers will be held in Boston, March 14, 1919. The headquarters of the Institute during the meeting will be at the Hotel Copley Plaza where all the technical sessions will be held.

The regular monthly meeting of the Board of Directors will be held at 2:30 p. m. in the Hotel Copley Plaza, and at 12:30 noon the members of the Board of Directors and guests will be entertained at luncheon by the Executive Committee of the Boston Section.

There will be morning, afternoon and evening technical sessions, and a subscription dinner will be given at the Hotel at 6:00 p. m.

The program will be as follows:

9:30 A. M.

Registration office opens.

10:00 A. M.

Railway Session

Addresses of welcome by His Excellency Governor Coolidge of Massachusetts and His Honor Mayor Peters of Boston.

1. *Some Possibilities of Steam Railroad Electrifiction as Affecting Future Policies*, by Calvert Townley.
   Discussions by W. S. Murray, Carl Schwartz, B. J. Arnold, George Gibbs, B. G. Lamme, H. B. Davis, P. M. Lincoln, E. W. Rice, Jr., E. M. Herr, W. B. Potter, N. W. Storer, and others.

12:30 P. M.

Luncheon given by members of the Executive Committee of Boston Section to members of Board of Directors and to guests.

2:00 P. M.

Telephone Session

2. *The Electromagnetic Theory of the Telephone Receiver with Special Reference to Motional Impedance*, by A. E. Kennelly and H. Nukiyama.
3. *On the Absolute Measurement of the Intensity of Sound*, by A. G. Webster.
   General discussion.

2:30 P. M.

Meeting of Board of Directors.

6:00 P. M.

Dinner at the Hotel Copley Plaza, $3.00 per plate.

7:45 P. M.

General Session

4. *University Training for Engineers*, by Charles W. Eliot.
5. *Science and the Engineer*, by Harry Clifford.
6. *Mathematics and the Engineer*, by E. B. Wilson.
7. *The Place of Science in Engineering*, by A. G. Webster.
8. *The Engineer and the University*, by B. G. Lamme.
9. *Our Mental Attitude Towards Scientific Investigation*, by Saul Dushman.
   General Discussion.

General Information

Hotels. Members from New York and the West arriving on the New York, New Haven and Hartford R. R., or the Boston and Albany R. R., should leave their trains at the Back Bay or Huntington Avenue Stations respectively.

Hotel reservations should be made in advance at the Copley Plaza at which all sessions will be held.

Other hotels are—The Vendome, Touraine, Somerset, Puritan, Parker House, Young's, Brunswick, Westminster. Rates from $2.00 to $5.00.

Dinner. Reservations for the dinner at 6:00 p. m. should be made as early as possible and should be addressed to Mr. B. A. Behrend, Chairman, Committee on Arrangements, John Hancock Building, Boston, Mass.

FUTURE A. I. E. E. MEETINGS

April Meeting.—The 349th meeting of the Institute will be held at Institute headquarters, 33 West 39th St., New York on April 11, 1919. This will be a joint meeting under the auspices of the Lighting and Illumination Committee and in conjunction with the Illuminating Engineering Society. Mr. George H. Stickney will present a paper for the A. I. E. E. on "The Present Status of Industrial Lighting Codes in the United States."

May Meeting.—The 350th meeting of the Institute will be the Annual Business Meeting held at Institute headquarters, New York, May 16, 1919. At this meeting the annual report of the Board of Directors will be presented and announcement made of the election of officers for the ensuing year. The feature of chief interest at this meeting will be the ceremonies in connection with the presentation of the Edison Medal.

Annual Convention.—It has been decided to hold the 35th Annual Convention of the American Institute of Electrical Engineers at the Lake Placid Club, Adirondacks, New York, during the week of June 23. Complete program and exact dates to be announced later.

FUTURE SECTION MEETINGS

Philadelphia.—March 10, 1919, Engineers' Club. Subject: The Power Situation.

Portland.—April 1, 1919. Subject: Concrete Ship Construction.

Schenectady.—March 7, 1919, Edison Club Hall. Subject: Soap Bubbles. Speaker: Dr. C. P. Steinmetz.

March 21, 1919, Edison Club Hall. Subject: The Education of Crippled Soldiers. Speaker: Prof. F. W. Sexton.

Washington.—March 11, [illegible] Subject: Economic Application [illegible] ity in the Industrial Plant [illegible] David B. Rushmore.

PLANS OF A. I. E. E. COMMITTEE ON DEVELOPMENT

To all Fellows, Members and Associates:

Your attention is earnestly invited to the two letters published below and relating to a newly created Committee on Development. This Committee will not succeed in its labors unless it can secure a clear composite of the views of the membership at large. A member of the Committee has been appointed or will be appointed from every Section. Every Institute member is earnestly urged to submit any suggestion he may have along the lines indicated or otherwise to his own Section member of the Committee on Development. Where a member is not affiliated with any Section, he is urged to send his suggestions direct to Secretary Hutchinson.

Very truly yours,
(Signed) CALVERT TOWNLEY
Chairman.

February 18, 1919

To Members of the Committee on Development.

Gentlemen:—

Pursuant to instructions contained in the resolutions of the Board of Directors, of which you were advised by the Secretary under date of January 27th, the Executive Committee of the Committee on Development held a meeting at Institute Headquarters on Feb. 4th, and following the line of procedure outlined by our President in his communication of January 27th, submits the following statement for your consideration:

The reconstruction or readjustment period following the close of the world war, and now upon us, has suggested to the four National Engineering Societies the advisability of a careful examination of their several organizations. The appointment, under one name or another, of committees similar to ours, evidences alertness to the situation and indicates a sincere desire that advantage shall be promptly taken to keep the national engineering organizations abreast, if not in advance of the world's march of progress. We understand it to be the duty and privilege of our committee to study the possibilities before our organization from every angle, and in due course to present any recommendations which commend themselves to us, whether they be fundamental on the one hand, or incidental on the other, or occupy any intermediate place between these two extremes.

The American Society of Civil Engineers has very well stated three major divisions into which the subjects which we are to consider may be separated, and we can perhaps do no better than to adopt these same divisions.

The Relations of the Institute to its Members

1. What, if anything, can properly be done to stimulate the interest of the individual member in the organization and to increase his participation in its activities?

(a) How can the Institute be made more useful to you, through its meetings, its PROCEEDINGS, or otherwise?

(b) In what way can you be more useful to the Institute?

2. Should the present method of holding stated and special meetings of the Institute and of its various Sections and Branches, at which technical papers are presented and discussed, be continued, either in its present form, or by either increased or diminished frequency of meetings, or under any change as to their scope and character?

3. Are there other forms of Institute activities in which we can engage with profit, either as substitutes for, or as supplementary to, our present activities?

4. What, if any, changes in the official organization and the method of conducting our affairs could be adopted to advantage? Can our present machinery for obtaining the collective views of our widely distributed membership be improved? If so, how?

The Relation of the Institute to Other Engineering Organizations

1. Is closer cooperation between the Institute and other engineering bodies, either local or national, desirable? If so, what is the best method in order to obtain the benefits of cooperation and at the same time to preserve the individuality of the bodies concerned?

2. Should the local sections of the national and perhaps other societies have joint local organizations or affiliations, and if so, to what extent should these be in addition to or substitutes for present practise?

3. Would it be desirable for the four national engineering societies, and perhaps others, to arrange to hold annual or less frequent coventions at the same time and place, so that what might be called an Engineering Congress could consider and pass upon the most important matters of common concern to engineers and upon those affecting public welfare?

Relation of the Institute to the Public

1. Should our organization become more active in the public affairs of the Cities, States, and Nation; and, if so, how can we most readily make our influence felt?

2. In what way, if any, can relations between engineers and the other professions be improved; also their relations with industry, finance, education, etc.?

3. In what other ways can the Institute take a useful part in connection with public affairs?

The foregoing questions are merely suggestive. It is not intended to exclude the consideration of any other matter. You are requested to give a most careful study to the various subjects before us and to stimulate discussion among your members. If possible appoint a local committee, and at your early convenience forward to the Executive Committee such suggestions as commend themselves to you. You are earnestly requested to make only concrete and constructive suggestions, and to specify as much in detail as possible how you think the suggestions can best be carried out.

Please give your attention to the matter of the cost of carrying out any plans which you may think desirable. Your attention is respectfully directed to the annual reports of the Treasurer as given in the TRANSACTIONS every year, and if you recommend any action requiring the expenditure of funds, please indicate how these are to be obtained, *i. e.*, whether by curtailment of any existing activities, and, if so, to what extent, or by the increase of our revenues, in which case from what sources the increases may be secured. It is, of course, obvious that the Institute has assumed certain duties and obligations in connection with the Engineering Societies Building, in which our headquarters are established, and it should be borne in mind that our organization with a membership of approximately 10,000 people, occupies an enviable position, not only in engineering, but in national affairs, which has been secured by consistently following a policy, the virtue of which has been demonstrated by its success and should therefore not be lightly modified or discarded. The task before us of keeping up with the times and at the same time of exercising a proper amount of conservatism can only be successfully accomplished if we all give it our best thought.

Very truly yours,
(Signed) CALVERT TOWNLEY,
Chairman.

January 27, 1919

To the Committee on Development of
American Institute of Electrical
Engineers.

On June 18th, 1918, the Board of Directors of the A. S. C. E. adopted resolutions directing the appointment of a Development Committee. These resolutions have been widely published and have doubtless come to your attention. Their substance was that in view of the changing social, economic, and industrial conditions in which the engineer has a large, if not a major, interest, it was well to take account of stock, in order to see whether or not a readjustment should be undertaken, such that the Society might "take its proper place in the larger sphere of influence and usefulness now opening to the profession."

The Development Committee of the A. S. C. E. consists of one representative from each local organization and seven members at large, and subjects proposed for its consideration are covered by three general heads: The Relations of the Society to Its Members; The Relation of the Society to Other Engineering Organizations; and the Relation of the Society to Public Affairs and Public Welfare.

This Committee has already held one meeting, divided up its work between several sub-committees, and adopted rules of procedure.

Later similar committees were appointed by the A. S. M. E. and the A. I. M. E.

The question of appointing a similar committee for the A. I. E. E. was very briefly considered at the meeting of the Board of Directors in August, 1918. It was pointed out, however, that a very similar purpose was served by our regular Section Delegates gathering at the Annual Convention, and no action was taken.

The question was again raised at the October meeting of the board, when the following resolution was passed:

RESOLVED, That a Committee on Development be appointed by the President to consider suggested or proposed modifications in the field and methods of work of the Institute, and to make recommendations to the Board of Directors concerning these matters.

The reasons for taking this action were two-fold.

First, it was realized on more careful consideration that our Section Delegates gatherings were chiefly devoted to the first of the three subjects assigned to the Development Committee of the A. S. C. E., namely, the relation of the Institute to its members, and that much good might be accomplished by a broader consideration of the purposes and scope of activities of the Institute, particularly when account is taken of the rapidly changing social, economic, and industrial conditions. Particular consideration may well be given to the part that the engineer should play in public affairs.

Second, that if all of the national engineering societies had similar committees dealing with the relations of these societies to each other, joint action of such committees would be not only desirable, but necessary, in order to secure results satisfactory to all.

Composition of the Development Committee of the A. I. E. E.

As it is of the utmost importance that the representation on such a committee be nation-wide, each Section has been asked to nominate a representative. Seven members at large have also been appointed by the President.

By authority of the Board of Directors, the President has also appointed an Executive Committee of seven members.

Suggested Procedure:

As it will be difficult to hold frequent meetings of such a widespread committee, even though the Institute were to defray the traveling expenses, which it is not now able to do, the following procedure is suggested:

(a) That the Executive Committee prepare a preliminary outline of the subjects to be considered, and such rules as may seem desirable for the efficient conduct of the work of the Committee, and distribute the same to all committee members.

(b) That each Section representative discuss the various subjects with his Section, or with the governing body thereof, and prepare such recommendations in relation thereto as may be agreed upon. These discussions should be thorough in character and thoroughly representative of the Section, since if any useful outcome of this movement is to be reached, the membership of the Institute must be aroused to its importance in the promotion of the interest of the profession and of the nation, and must be willing to give its time thereto.

(c) That the recommendations thus prepared be submitted to the Executive Committee for review, compilation, and reduction to their vital elements.

(d) That the resulting compilation in its simplest possible form be resubmitted to the Section representatives for further careful consideration by the Sections.

(e) That these further considerations be submitted to the Executive Committee for summarizing; and

(f) That this summary be submitted to the whole committee assembled at the Annual Convention of the Institute in June.

In this connection it is suggested that this meeting of the Development Committee in June replace the regular Section Delegates' meeting, or that the latter be transformed into a meeting of the Development Committee.

It should thus be possible to take some final action as to the recommendations of this Committee at the June Convention of 1919, and to submit to the Board of Directors at that time such recommendations.

If these recommendations should involve amendments to the Constitution, the machinery for such changes could be set in motion at once.

Finally, it is sincerely hoped and urged that this movement be given the serious consideration of the membership at large, and that each member of the Institute who has any suggestions submit them to his Section representative and take part when possible in the Section discussions.

Very truly yours,
(Signed.) C. A. Adams,
President.

Committee on Development

Townley, Calvert, *Chairman*, 165 Broadway, New York.

Brand, F. F., General Electric Co., Pittsfield, Mass.

Brunt, A., 5514 Wilkins Avenue, Pittsburgh, Pa.

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Clark, J. C., 270 Kellogg Avenue, Palo Alto, Cal.

Cushing, Ira M., 84 State Street, Boston, Mass.

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Dustin, F. G., Standard Electric Co.' Suite 240, Plymouth Bldg., Minneapolis, Minn.

Eales, H. W., 315 N. 12th Street, St. Louis, Mo.

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Ewart, F. R., 165 Grenadier Road, Toronto, Ont.

G[illegible]r, Baxter R., Gatun P. O., Canal Zone.

Hall, W. A., General Electric Co., West Lynn, Mass.

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James, W. F., 227 Mt. Pleasant Avenue, Mt. Airy, Philadelphia, Pa.

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Kline, J. J., General Electric Co., Fort Wayne Works, Fort Wayne, Ind.

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Lund, Charles A., W. 828 Providence Avenue, Spokane, Wash.

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Mac Dowell, A. S., Rochester Railway and Light Co., Rochester, N. Y.

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Robinson, L. T., General Electric Co., Schenectady, N. Y.

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Schuchardt, . R. F., Commonwealth Edison Co., 72 W. Adams Street, Chicago, Ill.

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Scott, C. F., Sheffield Scientific School, Yale University, New Haven, Conn.

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Snider, George E., Toledo Rlys. & Light Co., Toledo, Ohio.

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Schoen, A. M., Atlanta, Ga.

Scott, C. F., New Haven, Conn.

Wayne, J. L., 3d, Indianapolis, Ind.

A. I. E. E. MIDWINTER CONVENITON

The Seventh Annual Midwinter Convention of the American Institute of Electrical Engineers was held at Institute headquarters, New York, February 19 to 21, the total attendance of members and guests being about 1300.

Wednesday Afternoon

The opening session Wednesday afternoon was a joint session with the American Institute of Mining Engineers and was called to order by President C. A. Adams, who presided at this meeting. After a few words of welcome the Chairman introduced Mr. Leighton, the representative of the Engineering Council at Washington, who spoke briefly in regard to the past lack of activity of engineers in political affairs, and who outlined the plans of the Engineering Council which include a movement towards creation of a department of public works, a federal engineering department, under which all engineering activities of the government shall be correlated and presided over by a member of the engineering profession.

At the close of Mr. Leighton's address, Chairman Adams gave a brief explanation of the work of the Welding Committee, after which the five papers for the session were presented by their authors. This was followed by a spirited discussion by Messrs. W. H. Hill, H. A. Hornor, Captain Corbett, A. M. Candy, J. B. Murray, P. E. Hosegood, W. L. Merrill, Mr. Alexander, W. Spraragen, Mr. Hunter, and Commander Goodall.

Wednesday Evening

On Wednesday evening Dr. John A. Brashear delivered a lecture on "The New Astronomy" to an audience which completely filled the Auditorium. The lecture was accompanied by numerous lantern slides showing disturbances on the surface of the sun, which had never been shown before. This was followed by an exhibition of moving pictures accompanied by a brief address by Mr. Frank Lawton, Jr. These pictures illustrated the Operation of the Burroughs Adding Machine, the Telephone Receiver and Transmitter, and the Pneumatic Riveter. The last picture was of a humerous nature.

Thursday Morning

The second technical session was opened by President Adams at 10:30 A. M., who delivered an interesting address on various phases of standardization in engineering work. This address was followed by Dr. C. P. Steinmetz who presented in abstract his paper on "General Equations of the Electric Circuit," after which Mr. H. S. Osborne abstracted his paper on the subject of "Wave Shape Standard." The discussion which followed was participated in by J. B. Whitehead, C. R. Underhill, A. E. Kennelly, C. F. Scott, W. J. Foster, J. B. Taylor, J. J. Linebaugh, L. W. Chubb, and L. T. Robinson.

Thursday Afternoon

Thursday afternoon was set apart for technical excursions including inspection trips to the Brooklyn Navy Yard and to the Bell System Laboratories of the Western Electric Company. About 200 members and guests were transported from the Engineering Societies Building in busses to the foot of 23rd Street, where the Navy Department supplied large sea-going tugs to carry the party to the Navy Yard. The party spent an interesting afternoon inspecting the power plant, shops, drydocks, and various other features of the yard.

About 150 members and guests were taken from the Institute headquarters to the Western Electric Company's plant in cabs provided through the courtesy of the Company, and were divided into groups each of which under the leadership of a guide went through all of the Bell System Laboratories.

Thursday Evening

On Thursday evening at 7:00 p. m., 370 members and guests assembled at the Hotel Astor where a Dinner-Dance was held. This function, which in recent years has become a regular feature of the Midwinter Convention, was greatly enjoyed by all in attendance.

Friday Morning

By general agreement the sessions on Friday morning and afternoon were interchanged and at 10:30 o'clock President Adams called the meeting to order, after which Mr. Donald McNicol, Chairman of the Telegraphy and Telephony Committee took the chair. The Radio Telephony paper by Messrs. Craft and Colpitts was first presented followed by the paper on Transient Oscillations by Mr. Carson, and Telephone Circuits with Zero Mutual Induction by W. W. Crawford. The discussion was by George O. Squier, M. I. Pupin, Alfred H. Cowles and A. S. Dana.

Friday Afternoon

The final session of the convention was called together at 2:30 P. M. by President Adams, with Mr. F. W. Peek, Jr., Chairman of the Electrophysics Committee on the platform. The papers on Ionization of Occluded Gases in High-Tension Insulation by G. B. Shanklin and J. J. Matson, and Dielectric Strength of Air Films Entrapped in Solid Insulation by F. Dubsky, were presented in abstract and discussed by Messrs. H. G. Reist, L. W. Chubb, J. B. Whitehead, W. J. Foster, H. W. Fisher, R. E. Argersinger, F. W. Peek, Jr., C. Francis Harding, R. W. Atkinson, Delafield Du Bois, F. M. Farmer, and E. E. F. Creighton.

The last paper of the session on Abnormal Voltages in Transformers was then abstracted by Mr. L. F. Blume, and was discussed by E. E. F. Creighton, H. R. Summerhayes, G. Faccioli, F. Dubsky, L. W. Chubb, J. F. Peters, and F. W. Peek, Jr.

JOINT MEETING IN INDIA OF I. E. E. AND A. I. E. E. DECEMBER 30, 1918,- JANUARY 2-3, 1919

A three day joint meeting, the first of its kind in the annals of the Institute, and possibly the forerunner of similar annual meetings, was held in Calcutta, India, on December 30, 1918, and January 2 and 3, 1919, by local members of the British Institution of Electrical Engineers and the American Institute of Electrical Engineers. Papers were presented by N. N. Iengar, assistant to the chief electrical engineer, Government of Mysore, Dr. Alfred Hay of the Indian Institute of Science, Bangalore, and Mr. F. N. Mowdawalla.

The suggestion of inaugurating yearly joint meetings in India for the presentation and discussion of original papers, originated with Professor A. R. Nissar, of Bombay, in a letter to the Board of Directors of the A. I. E. E. Professor Nissar's communication was referred to the Institute's Local Honorary Secretary for India, Mr. Harry Parker Gibbs, who favored the idea, and after a conference by Mr. Gibbs with the Local Honorary Secretary of the Institution of Electrical Engineers, Mr. J. W. Meares, who also approved the suggestion, the meeting was arranged.

Mr. Gibbs presided at the meeting, and after preliminary opening remarks spoke in part as follows:

"We of the American group greatly appreciate the courtesy shown us on this occasion by our sister Institution, enabling us to participate with them in the privileges accorded to their own members, and I take this opportunity, for thanking their energetic Local Secretary, Mr. Hughman, for his good offices in connection with the provision of accommodation for our members while staying in this city for the purposes of this meeting. I sincerely hope that this our first joint meeting, may not be the last but may be followed by others and would say it is my personal feeling and opinion that it might with profit become an annual function.

"It will be in keeping with the occasion to make a few remarks concerning possibilities for the extended application of our electrical art in this great empire, followed by a few words regarding work on the western side of India in which I am most directly interested.

"I feel that India is essentially an agricultural country, and great wealth must accrue to the nation through extension and continued development of this great national asset, in connection with which our British and Indian engineers have set a mark and example for the rest of the world. Allied with such development various important industries must spring up, with which electrical engineering must play an important part. Among others which are now being investigated with intention of bringing into operation are the extraction of various oils, such as cocoanut, cotton, linseed, sandal; also sugar-making on a large scale, alcohol, acetone, scents, shipbuilding, bobbin making, and various other works. There are also to be exploited many important mineral deposits, and we shall have important industries in copper, aluminum, chemical fertilizers and so on, all requiring our assistance and cooperation in their development and transformation into the fabricated and marketable finished product useful in connection with our electrical engineering work.

"Now, once admitting that we as a body are destined to cooperate in such important national development, it seems to me to become with us an essential duty to individually try and impart uch special knowledge as we may possess to others round about us who are endeavoring to climb the ladder and achieve a position in our profession.

"With reference to our hydroelectric developments near Bombay in the Western Ghauts, I may say that, as a rule, the highest land is at the very edge of the ghauts having a rapid descent toward the west and a very gradual one toward the east. Near Lonavla it happens that this higher ground is broken away in such a manner that water impounded in lakes made by placing masonry dams across the lower ends of valleys could be led by open duct to a forebay from which the down-take pipes could be taken to the power house, approximately 1700 feet vertically below the forebay. This formed a natural type of development and the idea was conceived by the late Mr. Gostling, an architect and civil engineer of Bombay. This development comprising Lakes Gostling, Sydenham and Willingdon, is capable of supplying 50,000 electrical horse power or 135 million kilowatt-hours at the motor terminals in Bombay during 3600 hours per year.

"We soon realized that the original undertaking would be insufficient, and located the Andhra project, where the water is to be drawn off near the head of the valley through the scarp of the ghaut by means of a pressure tunnel with suitable surge chamber, the point of draw off being 115 feet vertical height above the lowest point in the river-bed at the site of the dam, so that the lake will impound 5000 millions of cubic feet of water below and 12,500 millions above draw off level, and supply 65,000 electrical horse power or 175.5 million kilowatt-hours at motor terminals. The Andhra development is well in hand the tunnel being three-fifths driven, while the foundations of the dam have been completed. The transmission distance to Bombay will be 56 miles.

"This investigation led to and was followed by that of the Nila Mula, which reservoir will be situated thirty miles west of Poona, where with a development similar in character to that of the Andhra, we can produce 150,000 electrical horsepower or 405 million kilowatt-hours per year. The surveys for this project are completed and the grant of the concession is now under consideration with the Government of Bombay. The transmission distance to Bombay will be 70 miles.

"Following the Andhra and the Nila

Mula explorations and based on similar methods of development came the great Koyna project further down the ghauts in a southerly direction, where it is estimated development is possible of such magnitude as to supply 300,000 electrical horse power day and night throughout the year. This project is now under survey, and we hope it will lead to the creation of a new and important industrial centre where electrochemical work on a large scale will be undertaken.

"In conclusion I wish to say that special thanks are due to members who have taken trouble to prepare and read papers, and we trust others hearing and seeing the same may be inspired to follow their example so that further gatherings will be arranged, and through them our members may become more generally acquainted with various works which are in operation and being undertaken."

DELEGATES TO FRANCE REPORT TO SOCIETIES

On the evening of February 10, 1919, a joint meeting of the four Founder Societies was held in the Engineering Societies Building, New York, for the purpose of hearing informal addresses by the delegates of these societies to the Engineering Congress held in Paris during December and January for the purpose of formulating plans for the restoration and development of French industry.

The delegation, as announced in the January PROCEEDINGS, sailed from New York December 5, 1918, and consisted of Messers. James F. Case, Chairman, George W. Fuller, A. M. Hunt, Nelson P. Lewis, Charles T. Main, E. Gybbon Spilsbury, Lewis B. Stillwell, George F. Swain, and George W. Tillson.

Col. Herbert S. Crocker, Vice-President, American Society of Civil Engineers, presided at the meeting, which was attended by about 500 members and guests of the Founder Societies.

The following is an abstract of the remarks made by the various delegates.

GEORGE F. SWAIN. In March, 1918, there was held a Congress of engineers in France, and this Congress is still in existence. It was gotten up and carried on by business men, manufacturers, public men, and engineers, to deal with problems of engineering. The Chairman was M. Millerand, who was Minister of War at the beginning of the war. One meeting of the Congress was presided over by M. Clementel, Minister of Commerce. They wanted to consult with American engineers on engineering problems of reconstruction. This does not mean the building up of the destroyed districts. Reconstruction has three stages in France: first, the conversion of industries from a war to a peace basis.

Then, second, would come the rebuilding of the devasted districts; and, third, would come the great engineering problems which face France. It was with the last of these problems that this commission had to do.

This Congress was divided into committees, and the committees were on ports, navigable waterways, roads, agriculture, rural sanitation and hygiene, water power, and technical education.

We arrived in France on December 16th, and sailed on January 18th. We went straight to Paris, and there had meetings with the various committees of the Congress; we met the Chairman and the engineers connected with those committees, and discussed the problems with them. We have still several reports to prepare and send back to them.

The French engineers are very anxious to cooperate with American engineers. They want to get American capital for France, and to learn American methods of work. They are very much surprised, I think, by the work that American engineers have done there; and they think that possibly by cooperating in the future, both countries will be benefited. I thoroughly believe that such is the case.

At the last meeting of the Congress, M. Millerand was very earnest in urging that a permanent Franco-American International Committee should be appointed. The Congress voted at its last meeting in favor of the appointment of such a committee, and appointed as the French members the Chairmen of all the various committees with whom we had been dealing—the very men with whom we had been in contact for a month in France.

Before leaving France we presented a preliminary report to the French engineers. This report answered questions they had asked, and expressed our views on the various resolutions which had been passed at the first meeting of the Congress in March last, all of which we had in our possession before we left here.

We are now preparing a report, which will be submitted to the four National Engineering Societies, describing our work in detail.

The French have great plans for internal navigation. They must develop their ports, if they are going to take care of the traffic which formerly went to North Sea ports, to Bremen and Hamburg, and which they hope will hereafter go through France. The French have been planning very great works of improvement for their ports, but, of course, they have to provide the transportation inland from them, and that can be either by rail or by waterway.

They seem to have a great idea of developing waterways. That was the only point, I think, in which the members of the delegation were not—and certainly I myself was not quite—in sympathy with the French engineers. We saw plans for spending large sums of money in building canals and making rivers navigable, but we saw not one study of the economies of any of those questions; no statistics of transportation, no study as to whether they could get any return on the expenditure.

One of our committees had to deal with technical education. Such education in France appears to have been very theoretical.

I think the French realize that, with them as with us, the events of the last few years ought to lead to changes in educational methods. One great thing is to have one nation learn from another; and the best time to learn is when a man is young. We emphasized at every opportunity the desirability of having Americans go to France to study and Frenchmen come to America to study.

G. W. TILLSON. The French gave us certain subjects which they wished us to consider. One subject was "Roads," to which Mr. Lewis and myself were specially assigned.

Our method of procedure over there, in general, was that our committees should meet with their committees on the same subject; and our Committee on Roads met the Committee on Roads of the Congress, which was headed by M. Heude, formerly Inspector General of the "Pontset Chaussées". The French understood from the severe traffic during the war that their old roads would not stand up under that which was to come, and also that, owing to the lack of attention given them during the war, there was a great deal of work to be done at this time.

The members of our committee urged the consideration of other types of roads, such as concrete and brick. We told them of the concrete roads which had been built in America during the past 10 years, and the good results that had been obtained, and that they could expect good results in France because their climate is more favorable, without the extremes of temperature which we have, and which cause cracks in the concrete.

They asked us specifically, "Will American contractors come over here and do road work, and take their pay in 15 annual installments?" We told them, "Yes, but you must understand this: First, they must have absolute and positive arrangements made for the payments, as to which there must be no question; and, secondly, if you pay them in that way, you will pay 60 or 75% more for the work than you would if you paid when it was completed."

That did not seem to appeal to them. We pointed out that if they were to issue serial bonds, say for 15 years, and pay the contractor in full when the work was done, the interest and principal sum would be much less.

E. Gybbon Spilsbury. A visit to the battlefronts and the devastated region in the northwest of France is still a matter of some difficulty, and can only be undertaken with the permission and under the auspices of the French Government.

We were specially favored as guests of the Government, and had attached to our party a Captain of the French Army, who had been engaged on that front during the war, and who made a splendid guide.

The Government also detailed Col. Cuvelet, the Chief Mining Engineer of the Lens Coal Mining District, to accompany us.

Of the town of Lens itself and the sixty or more mining shafts, not a building or a head-frame remains standing, everything is levelled with the ground. Yes, there is one eminence remaining, the pile of debris caused by the destruction of the Cathedral. Terrible as this is, however, it was the fate of war, but the destruction of the mines, with the view of crippling the whole of the French industrial life, is far worse than the mere razing of the houses.

In the Lens district, there were in all some sixty mines, large and small.

As there will be little or no coal available until the mines are de-watered, they propose running their pumping machinery by electricity.

It is estimated that it will take 30,000 h.p. for a full year and a half for this de-watering. They have a small surface coal deposit about 12 miles from Lens, where they are now building a power station from which to run the pumps.

It is expected that coal mining in the upper seams will probably begin in about a year.

One of the great difficulties will be the clearing away of the wreckage, owing to the habit the Germans had of connecting pieces of structural material with mines or explosives. The whole place is also full of unexploded shells and grenades. Hardly a day passes but some one is injured by these explosions.

There is one thing that I want to impress on you, and that is, that the French people are not lying down and waiting for the expected amounts that they will receive from Germany before starting to reconstruct the work upon these lands.

Another thing was very apparent to us, and that is that they are not seeking the help of any foreign engineers to aid in this work. They have plenty of talent of their own, and they are going to use it.

George W. Fuller. To France, the close of the war means the development of commercial and industrial procedures so that the annual budget, including its various political subdivisions, may be increased to a sum 10,000,000,000 francs in excess of what it was before the war.

Agriculture is one of the basic sources of wealth of the nation, and the agricultural section devoted much attention to discussion of improving banking facilities.

American customs as to handling meats in central slaughter houses, in conjunction with cold storage plants and refrigerator cars, could be adopted advantageously by the French. The same is true as regards the more general use of drying for the preservation of fruits.

Agricultural implements have disappeared from the devastated areas, and are greatly depleted throughout France. Munition factories will be converted to the manufacture of some lines. For some equipment the French would like to see Franco-American concerns established. Each proposition, from financial, commercial, and engineering standpoints, should be carefully investigated on its own merits.

Rural sanitation in France—as elsewhere—is largely a question of an effective campaign of education. The French members were interested to learn of steps taken in America to teach personal hygiene in the schools.

L. B. **Stillwell**. The Water Power Committee appointed by the delegation of American Engineers was composed of Mr. Hunt, Dr. Swain, Mr. Main, and myself. The Chairman of the Water Power Committee of the Congress was M. Blanchet, chief administrator of one of the important French railways, and a man who is exceedingly well informed as to the general problems of water power development.

The Committee, after having held several sessions in Paris on December 19th and 20th, arrived in Grenoble on January 5th, and a long session was held and several engineers described the projects for the development of water power particularly in the Valley of the Upper Rhône.

Following our return to Paris another session was held at which other projects were described.

The total horse-power of France, in round numbers, based on the estimate of French engineers as to what proportion of the power is, or will in the near future be, commercially developable, is from 5,000,000 to 6,000,000. I believe it would be safer to consider 4,500,000 h. p., as the total that may be commercially developed, and 9,000,000 h. p. as the total available for 6 months of the year.

The coal consumption in France in the average year immediately preceding the war was about 60,000,000—it was 62,000,000 tons in 1913. Of this total about two-thirds are produced by French mines and one-third is imported.

The average price prior to the war was from $5 to $6 a ton. The judgment of the engineers with whom I talked was that a considerable number of years would elapse, following the termination of the war, before the price of coal will be below $8 a ton. It is obvious, therefore, that there exists an extremely practical and cogent reason for the prompt development of French water powers as a substitute for the use of coal.

In the United States, as you know, the figure before the war representing the output of our industries was about $1500 per h. p. used by American mills and factories. If you could utilize even one-half the water powers of France, the immense value of the factories and mills which could be supplied with that power can be easily imagined, and the number of operatives required by these mills, according to the figures prevailing in the United States would approximate 500,000.

One thing that is notable over there in regard to their utilization of water powers in their tendency to take the industry to the water power. In the tributaries of the Rhône there are many plants; not many of them are large, but they are numerous, and the processes in electro-chemical work and metallurgical work are varied and extremely interesting. The ratio of installed capacity to the average low-water flow, is about 3.5, which indicates that they are in many cases using power for less than 12 months in the year, and find it advantageous to put in apparatus even where the water is not available all the time.

Apparently, they have not thus far given a great deal of attention to the combination of steam power with water power. There are considerable deposits of coal, but of very poor quality, in the immediate vicinity of water power.

In our preliminary report we called attention to the fact that the ultimate solution of their problem would probably be to connect some of their coal regions with their water powers, and utilize the steam plants to convert secondary power to primary power as the demand may grow.

We saw at Grenoble several of the sub-stations at which power was received by transmission from the Alps, and we were particularly interested in examining the famous Thury system, which has been in operation now for some 20 years. That plant, as you may remember, utilizes continuous current at a constant rate of about 130 amperes, the voltage varying from 40,000 to 65,000, depending on the load. The receiving apparatus consists of pairs of motors, each motor having a potential of 3500 volts across its commutator, a number of these pairs being connected in series. At low loads the efficiency of the system must be far from satisfactory, but the plant has been constructed with very great care and skill, as shown by the fact that in all these years they have had only one fatal accident in handling their high potential.

I noted, however, on the same pole line which carries the direct current, that there are conductors for the alternating current system, and they are now using six conductors, two 3-wire circuits for alternating current at 45,000 volts, through which they are transmitting 15,000 kw. as compared with 10,000 kw. for the direct current, showing that, having tried the direct current, they have swung over to the alternating three-phase current, as generally used in America.

As regards the electrification of railways, the French have not done a great deal, although they were among the first to apply electricity to railway operation. M. Sabouret, Chief Engineer of the Paris and Orleans Railway, read an admirable, brief paper describing the present condition of the electrification of the railways. I was interested to note that the history of the application of electricity to haulage in France illustrates in a striking way the old adage that "a prophet is not without honor, save in his own country." The electric locomotives for the operation of the Baltimore Tunnel of the Baltimore and Ohio Railroad were introduced about 1898, certainly prior to 1900. The French company sent engineers over here to examine the operation of the railroads, and they reported that the solution of the problem of the haulage of trains from the Austerlitz station to the Quay D'Orsay was perfectly clear, that the electric locomotive should be used, and since 1900 they have been operating trains between those two points in that way.

During later years, when the Pennsylvania Railroad was considering the electrification of its terminal in New York City, the Vice-President, knowing that Mr. Cassatt, the President, was in France, cabled him that the French were using electricity to haul trains on the Orleans Railway, and Mr. Cassatt examined it and reported back that the problem was solved.

Prior to the war, the French engineers were making careful study of the problems of electrifying the Midi Railway, and contemplated some elaborate tests. The war stopped all that, but they still have it in mind, and engineers representing three of the French railways expect to come here soon to see what we have been doing since they last examined the work in America. They do not expect to electrify their entire systems, of course, but there are certain sections of France, where the roads are within reach of water powers, and other sections where the traffic is dense, which they think it will pay to electrify.

As regards the laws under which water powers are utilized, the French are in very much the same position as we are. They are seeking for a general law governing water power relations. The power developments heretofore have been made either under authorizations which are revocable or under special concessions which are not always easily obtained. They now have in the House of Deputies a bill to establish a general law of concessions under which it is hoped that capital will be attracted to the development of their water powers, as they have not heretofore been developed on a scale commensurate with their possibilities.

A. M. HUNT. Owing to the absence of Major J. F. Case, who was Chairman of the Committee on Ports, I have been asked to comment on this subject.

The French authorities have distinctly in view an effort to make their ports serve, not only the needs of France, but to make them ports of entry for middle Europe. To accomplish this, they contemplate an east and west railroad line from one or more of their Atlantic ports, over which freight arriving at such ports can be expeditiously and economically carried across France to some point in Switzerland, for instance Basle, and from such point to destination.

An ambitious project is being talked of, which contemplates making St. Nazaire the port of entry, from which place a very easy grade up the Loire River and to Basle can be followed. By utilizing existing railway lines, this route could be established in a minimum of time.

The French engineers realize that if they are to capture this trade, which before the war went through German ports, they must act promptly. To this end, this project contemplates taking over the plant which our Army has been constructing near St. Nazaire to supplement the previously existing facilities at that port.

The range of tides at the Atlantic ports of France is from 6 to 8 m., or 19 to 26 ft. For handling vessels and discharging them, the French engineers have in most cases limited themselves to wet basins with locks.

The French engineers requested a report on the subject, with data as to the handling methods at American ports having extreme ranges of tide, and such a report will be sent them by members of our delegation.

Our Committee made the following recommendation in our written report to the Congrès du Génie Civil:

"The Committee believes that the Congress would do well to study the methods in use in America for loading and unloading facilities alongside the wharves, even where there is a considerable range of tide, without the use of enclosed basins entered through locks. Experience in our ports and at Panama has demonstrated that locks are not necessary even when the range of tide is very considerable. If the docks are equipped with proper mechanical devices for loading and unloading it makes little difference whether the vessel stands high or low at the dock. The Committee will not attempt to fix the limit of tide above which locks should be used, but at some American ports they have not been found necessary with a range of tide of 6 or 7 m."

The French engineers also desired specific information regarding floating docks. Information as to our practise in this line is being secured and will be sent to them.

Nelson P. Lewis. I was asked to say something of the visit to the Marne Valley and Chateau-Thierry. We followed the direct road to Meaux, one of the main roads of France, the trees along which had been cut down in order that they might not furnish a target for hostile air raiders, but new trees have already been planted.

Now, a few words on general impressions: First, let me speak of the social conditions which have been caused by the War. The most conspicuous of these, perhaps, is the separation of families. The entire Northern war zone is depopulated; the able-bodied men were in the army and all the others have gone elsewhere, most of them to Southern France, where they have been employed in war industries, earning more money than they ever dreamed of before, and living in a more equable climate. The great problem is whether they will want to go back.

In talking about the social conditions, we must take into account the change which has come over the women of France. They have been wonderfully brave and loyal, and it was pathetic to us at first to see them doing the hard, rough work of porters at the railway stations, but they looked well and well-nourished, and it does not seem to have disagreed with them.

There will scarcely be an immediate revival of the fine art manufactures and the production of luxuries for which France was famous before the war, but they must turn their attention to the essential things that France needs in order to live and to recover its prosperity.

There is, then, an unbalanced industrial country; a part of it almost depopulated, the other part developed with a series of industries new to France and not now needed; and these must be replaced by others.

As to the extent of the damages to industry, we were furnished some figures, and I have taken only those which were most conservative. Some of the estimates are far higher. The devastated area covered 6000 sq. miles, and in that district it is estimated that 500,000 buildings were damaged; one-half of which were totally destroyed. It is estimated that 500,000 men of the building trades would be continuously employed for 15 years in restoring these buildings.

Reduced to money, the estimated damages are about as follows:

Buildings destroyed or damaged.	$ 4,000,000,000
Furniture destroyed or stolen....	1,000,000,000
Public works wrecked..........	2,000,000,000
Farm lands damaged...........	800,000,000
Live stock, agricultural implements, and forests..........	1,200,000,000
Mines and steel works..........	700,000,000
Miscellaneous industrial machinery and raw material destroyed or stolen........	4,000,000,000
Total...............	$13,700,000,000

This does not include Belgium, and we must not forget Belgium.

Now, is this amount, representing, not the cost of the war to France, but simply the physical damage sustained by her, to be paid by Germany? It should be paid to the last dollar; notwithstanding the whine we hear from the other side of the Rhine.

INSTITUTE OF RADIO ENGINEERS

A joint meeting of The Institute of Radio Engineers and The New York Electrical Society will be held on the evening of Wednesday, March 5, 1919, 8:15 P. M., in the Assembly Room No. 2 of the Engineering Societies Building, 29 West 39th Street, New York.

A paper will be presented on "Reception Through Strays and Interference" by Mr. Roy A. Weagant, Chief Engineer of the Marconi Wireless Telegraph Company of America. In view of the great importance of the elimination of strays in radio, this paper will be of great practical interest.

Members of the A. I. E. E. and others interested are cordially invited to attend.

DISMISSAL OF PUBLIC SERVICE COMMISSION ENGINEERS IN NEW YORK CITY

January 6, 1919, an urgent meeting of the Executive Committee of Engineering Council was called to determine what action it could take concerning the sudden dismissal, by the Public Service Commission for the First District of New York, of approximately 350 engineers and assistants engaged on subway construction. This dismissal was forced by action of the Board of Estimate and Apportionment of the City in the adoption of a segregated line budget. It was decided that a hearing should be held, if suitable requests therefor were made. Communications having been received from the Acting-Chairman of the Public Service Commission, American Society of Civil Engineers, Brooklyn Engineer's Club, The Municipal Engineers of the City of New York, also a petition signed by more than fifty engineers, a special committee was appointed and a hearing held in Engineering Societies Building January 14. The members of this committee were Harold W. Buck, Chairman, C. A. Adams, C. W. Baker, N. A. Carle, George J. Foran, Allen Hazen, Clemens Herschel, Alex. C. Humphreys, D. S. Jacobus, J. F. Sanborn, J. Waldo Smith and Herman Aaron, Counsel. To this hearing were invited the City authorities, engineers and civic associations interested. There was an attendance of about 50 persons, and the facts of the case were well presented. A printed statement of the findings was sent to the Board of Estimate, the Public Service Commission and its engineers, the Governor, more than 100 civic and trade associations in New York, many engineering societies throughout the country, daily newspapers, and the technical journals, as well as the representatives on Engineering Council. At the end of January, the City authorities made provision for restoring most of the engineers to their positions and continuing the subway construction. Some of the dismissed engineers, it is reported, will receive pay also for January. Letters recently received from the Acting Chairman, the Chief Engineer and the Engineer of Subway Construction of the Public Service Commission expressed appreciation of Council's efforts, and stated that they had been effective.

PAST SECTION MEETINGS

Baltimore.—Belvedere Hotel, December 18, 1918. Illustrated lecture by Mr. H. L. Hess on "Electric Furnace as Applied to Steel Making". Joint meeting with local section of A. S. M. E. Attendance 70.

January 31, 1919, City Club. Illustrated address by Colonel William H. Walker on "The Manufacture and Use of Toxic Gases". Joint meeting with Maryland Section of American Chemical Society. Attendance 125.

Boston.—February 4, 1919, Engineers Club. Illustrated lecture by Dr. A. E. Kennelly on "Some Features of Electrical Engineering in the War." Attendance 100.

Chicago.—January 27, 1919, Western Society of Engineers Rooms. Paper: "The American Beet Sugar Industry" by M. J. Kermer. The paper was illustrated by lantern slides and moving pictures. Joint meeting with Western Society of Engineers, and local sections of American Society of Mechanical Engineers and American Society of Chemical Engineers. Attendance 175.

Cleveland.—January 20, 1919, Electrical League. Illustrated address by Mr. A. H. Rudd on Railway Signals." Attendance 85.

Denver.—January 18, 1919, Denver Athletic Club. Address by Mr. Franklin P. Wood on "The Future of Public Utilities as Affected by the War." Attendance 68.

February 15, 1919, Denver Athletic Club. Illustrated address by Mr. G. N. Robinson on "Electric Welding." Attendance 50.

Detroit-Ann Arbor.—January 31, 1919, Detroit Board of Commerce. Paper: "Direct-Current Generators" by Prof. H. H. Higbie. Attendance 65.

February 14, 1919, Detroit Board of Commerce. Paper: "Automatic Control of Railway Substations" by Cassius Davis. Attendance 68

Erie.—February 11, 1919, Board of Commerce Rooms. Paper: "Electric Welding in Shipbuilding" by Comfort A. Adams. Attendance 250.

Fort Wayne.—January 23, 1919, Building 16-2, General Electric Company. Short address by Captain Walter Kent, followed by motion pictures showing Submarines, Destroyers, Fire and Gas, supplied by courtesy of Committee on Public Information. Motion picture was also shown illustrating manufacture of electrical porcelain at the Schenectady Works of the General Electric Company. Attendance 22.

February 20, 1919, Building 16-2, General Electric Company. Address by Mr. E. A. Barnes on "The Industrial Derelict." Attendance 36.

Indianapolis-Lafayette.—January 23-24-25, 1919, Claypool Hotel. Papers: (1) "Public Utilities in the War Period" by H. O. Garman; (2) "Psychological Methods of Selection of Soldiers, Officers and Employees" by C. F. Harding; (3) "Efficiency Engineering in Industrial Plants" by J. E. Hannum; (4) "Some Recent Technical Developments in Telephony" by R. V. Achatz; (5) "Electrical Pumps in Municipal Water Works" by D. D. Ewing; (6) "The Decimal Versus the Dozen System of Writing Numbers" by John D. Riggs. Annual meeting of Indiana Engineering

Society in which Indianapolis-Lafayette Section participated. Attendance 40.

Lynn.—January 22, 1919, General Electrical Hall. Address by Rear Admiral John R. Edwards, U. S. N. (Retired) on the "Industrial Features of the Modern Navy." Attendance 176.

February 12, 1919, General Electric Hall. Illustrated address by Mr. C. A. Kelsey on "The Sugar Industry." Attendance 210.

Madison.—January 10, 1919, Engineering Building, University of Wisconsin. Discussion of Losses in the Low Radio Antenna by Professors Edward Bennett and E. M. Terry, and Mr. H. M. Crothers. Attendance 27.

February 11, 1919, Physics Building. Paper: "Bulbs and Their Uses in Radio Telephony" by E. M. Terry. Attendance 90.

Panama.—December 22, 1919, Balboa Heights. Paper: "The Influence of Modern Illuminants upon Industrial Economy and Efficiency" by L. W. Lewis. Attendance 32.

Philadelphia.—January 13, 1919, Engineers' Club. Paper: "Lighting in War Time" by Preston S. Millar. Joint meeting with Philadelphia Section of Illuminating Engineering Society. Attendance 89.

Pittsburgh.—January 14, 1919, Chamber of Commerce Auditorium. Paper: "Passenger Transportation Problems during the War" by J. W. Welsh. Attendance 85.

February 11, 1919, Chamber of Commerce Auditorium. Paper: "Some Problems in Parallel Operation of Power Plants" by C. E. Stone. Attendance 95.

Pittsfield.—January 9, 1919, High School Auditorium. Illustrated Lecture by Colonel R. H. C. Kelton on "The Situation at Chateau Thierry." Attendance 650.

January 23, 1919, New American Hotel. Illustrated lecture by Mr. Langdon Gibson on "The First Peary Expedition of 1891". Attendance 175.

Portland.—January 7, 1919. Lecture by Dr. Morgan on "Chemistry of the War." Attendance 105.

February 4, 1919. Paper: "Laying a Deep Water Submarine Telephone Cable" by H. J. Sheppard. Paper was illustrated by lantern slides and moving pictures. Attendance 55.

St. Louis.—January 28, 1919, American Hotel Annex. Address by Dr. J. J. Kessler on "Materials of Machine Insulation." Election of officers as follows—chairman, J. L. Hamilton; secretary-treasurer, H. G. Hake. Attendance 38.

San Francisco.—January 24, 1919, Engineers Club. Subject: A Symposium on Engineering Education. Speakers: Drs. C. L. Cory and C. D. Marx, and Messrs. J. W. Beckman, John A. Britton, and T. A. Rickard. Joint meeting of San Francisco Sections of A. S. M. E., A. S. C. E., A. I. M. E., A. C. S., and A. I. E. E. Attendance 200.

Schenectady.—January 16, 1919, Edison Club Hall. Paper: "Turners Falls Power and Electric Company System" by F. L. Hunt. Paper was illustrated by lantern slides. Attendance 175.

February 7, 1919, Edison Club Hall. Address by Dr. Frank R. Rutter on "Our Foreign Commercial Relations." Attendance 250.

Seattle.—January 21, 1919, Arctic Club Building. Illustrated address by Mr. Norwood W. Brockett on "Experiences during the Last Year of the War in France." Attendance 47.

Spokane.—January 17, 1919, Chamber of Commerce. Paper: "Big Bend Irrigation Project" by J. C. Ralston. Joint meeting with local sections of A. I. M. E., A. S. C. E., and Spokane Engineering and Technical Association. Attendance 51.

Toronto.—January 17, 1919, Engineers' Club. Illustrated lecture by Mr. R. C. Harris on "The Bloor Street Viaduct." Attendance 50.

January 31, 1919, Toronto University. Illustrated address by Mr. J. F. Heffron on "Recent Advances in Illumination." Attendance 80.

February 7, 1919, Engineers' Club. Paper: "The Manufacture of Electrical Porcelain" by Hugo J. Lundgren. Attendance 60.

Washington.—February 11, 1919, Cosmos Club. Illustrated lecture by Mr. H. A. Hornor on "Electric Welding in the Ship Industry." Attendance 250.

PAST BRANCH MEETINGS

University of Arkansas.—January 30, 1919. Election of officers as follows—chairman, William L. Teague; vice-chairman, J. C. Black; secretary-treasurer, B. R. Askew.

February 6, 1919. Address by Prof. F. G. Baender on "The Making of a Successful Engineer." Attendance 30.

University of Maine.—January 6, 1919. Election of officers as follows—president, Ray C. Hopkins; vice-president, Lester C. Swicker; treasurer, Frank A. Tracy; secretary, Lloyd R. Douglass. Addresses as follows—(1) "Advantages of Electric Traction" by Prof. Hills; (2) "The Prospects of the Electrical Engineering Profession" by Prof. Barrows. Attendance 30.

February 6, 1919, Lord Hall. Illustrated lectures as follows—(1) "The Panama Canal" by W. C. Ellsworth; (2) "Electricity on the Farm" by Mr. Hopkins. Attendance 25.

University of Michigan.—January 28, 1919, Engineering Building. Address by Prof. J. C. Parker on "The Engineer in the Future." Attendance 54.

Michigan Agricultural College.—February 13, 1919. Paper: "High-Frequency Current and Its Applications". by Mr. Andres. Election of officers as follows—chairman, R. A. Shenefiel; secretary-treasurer, W. A. Siefert; executive committee, M. M. Cory, W. E. Thomas, R. W. Noddins; program committee, H. G. Carrow, A. P. Bock, and R. B. Kling. Attendance 17.

University of Missouri.—February 3, 1919, Engineering Building. Papers: (1) "Experiences with Public Utilities" by B. J. George; (2) "Experiences with Manufacturing Company" by W. D. Virture; (3) "Experiences with Telephone Utilities" by L. F. Remley. Attendance 23.

Montana State College.—January 29, 1919, Electric Building. Address by Mr. Carl Ladenburg on "The Westinghouse Student Course." Attendance 24.

University of North Carolina.—January 30, 1919, Chapel Hill. Address by Prof. P. H. Daggett on "Electrical Engineering, Yesterday, To-Day, and To-Morrow." Attendance 26.

Ohio Northern University.—January 15, 1919, Dukes' Memorial. Address by Mr. D. C. Jackson on "The Production of Crude Oil." Attendance 14.

January 29, 1919, Dukes Memorial. Papers: (1) "Radio Work in the U. S. Army" by Morris Elder; (2) "Mines and Mining in British Columbia and Montana" by Frank Davidson. Attendance 15.

Purdue University.—January 21, 1919. Address by Prof. C. F. Harding on "Aims and Purposes of A. I. E. E." Moving picture film "The Electrical Giant" through courtesy of General Electric Company. Attendance 150.

February 4, 1919. Paper: "Service at Cost" by R. W. Lovering. Election of officers as follows—vice-president, M. V. Merriman; treasurer, E. V. Emery. Attendance 70.

A. & M. College of Texas.—January 22, 1919. Election of officers as follows: —chairman, F. Murrah; secretary-treasurer, C. R. Drake. Attendance 36.

Virginia Polytechnic Institute.—January 28, 1919. Moving picture entitled "The Life and Work of Thomas A. Edison," by courtesy of General Electric Company. Attendance 341.

February 11, 1919. Moving picture entitled "The Electrification of the Panama Canal" by courtesy of General Electric Company. Attendance 291.

University of Washington.—February 4, 1919, Forestry Hall. Paper:

"Wave Form" by L. F. Curtis. Attendance 13.

State College of Washington.—January 24, 1919, Mechanic Arts Building. Address by Dean H. V. Carpenter on "The Question of Heating by Electricity in Idaho." Attendance 21.

February 14, 1919. Address by Prof. O. L. Waller on "How You Expect to Sell Your Services." Attendance 16.

Washington University.—January 24, 1919. Paper: "Electric Equipment for Automobiles" by Mr. Weichsel. Attendance 25.

ASSOCIATES ELECTED FEBRUARY 19, 1919

*Abbot, George, Cable Tester, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

*Abrahams, Alfred A., Telephone Engineer, Bell Telephone Co. of Pa.; res., 3726 N. 19th St., Philadelphia, Pa.

Adams, Royce Elmer, Electrical Gunner, U. S. N. R. F., Commonwealth Pier, Boston; res., 47 Wilbur St., Everett, Mass.

*Addy, John G., Jr., Asst. Inspector of Engineering Material, U. S. N.; res., 298 St. Johns Place, Brooklyn, N. Y.

*Allwein, Aloysius Francis, Electrical Engineer, General Electric Co.; res., 866 Union St., Schenectady, N.Y.

*Ambrose, George, Foreman, Power House Construction, Goodyear Tire & Rubber Co.; res., 1458 Malasia Road, Akron, Ohio.

*Anderson, Joel E., 2nd Lieut., Chemical Warfare Service, U. S. Army; res., 150 Comstock St., Joliet, Ill.

*Anderson, Squire Hamilton, Machinery Switchboard Branch, Western Electric Co., 463 West St.; res., 116 W. 13th St., New York, N. Y.

Arany, Leo, Radio Installation Engineer, Kilbourne & Clark Mfg. Co., 149 Broadway; res., 548 East 183rd St., New York, N. Y.

*Arlin, Harold Wampler, Statistician, Employment Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

*Atchison, Thomas Calvin, 2nd Lieutenent, Air Service, U. S. Army; res., 45 Hillside Ave., Lawrence, Mass.

*Aznar, Luis Fernando, Foreign Dept., General Electric Co., Schenectady, N. Y.; res., 1720 Spring Garden St., Philadelphia, Pa.

Babbitt, Albert K., Engineer in Charge, Cold Storage Plant, Naval Operating Base, Hampton Roads; res., 506 Mowbray Arch, Norfolk, Va.

*Badger, Henry Stillman, Asst. Division Inspector, Public Service Co. of No. Illinois, Chicago Heights, Ill.

Bagnall, Frederick Wm., Overhead Maintenance Dept., Detroit Edison Co., 1700 David Whitney Bldg., Detroit, Mich.

*Barney, Eugene Judson, Technical Correspondent, The Domestic Engineering Co.; res., 21 Seminary Ave., Dayton, Ohio.

Baxter, Channing Wheeler, Electrical Draftsman, Bureau of Steam Engineering, Navy Department, Washington, D. C.; res., 173 Columbia Heights, Brooklyn, N. Y.

Beatty, Frank S., Power Dept., American International Shipbuilding Corp., Hog Island; res., 5834 Washington Ave., Philadelphia, Pa.

Bergstein, Isidore, Electrical Engineer, 845 Beck St., New York, N. Y.

Betts, Anthony J., Chief Electrician, Columbus Barracks, Columbus, Ohio.

Bowen, William Earl, In Charge Radio Laboratory, Norfolk Navy Yard, Portsmouth; res., 370 W. 12th St., Norfolk, Va.

*Bowman, George Monroe, Ensign (Engineering), U. S. N. R. F.; res., 3128 Oak St., Kansas City, Mo.

Bradley, William Tully, Supt., Elec. Construction, Submarine Boat Corp., Newark Bay Shipyard; res., 301 So. 18th St., Newark, N. J.

*Brentlinger, Clell McArthur, Engg. Asst., Vice-Pres., in Charge of Traffic, Western Union Telegraph Co., New York, N. Y.

Brock, George, Electrical Draftsman, Western Elec. Co., 72 W. Adams St., Chicago; res., Oak Park, Ill.

Brooks, Harry Glenn, Electrical Ensign, U. S. N. R. F., 703 Terminal Annex Bldg.; res., 3906 Spruce St., Philadelphia, Pa.

Brussell, Clarence J., Chief Electrician, U. S. Navy, 1121 Bedford Ave., Brooklyn, N. Y.

*__Burger, Emmett E.__, Company F,37th Engineers, U. S. Army; res., 909 Plum St., Erie, Pa.

*__Butler, Thomas William__, Ensign, U. S. N. R. F., U. S. Naval Experimental Station; res., 184 Willetts Ave., New London, Conn.

*__Chadwick, Gilbert Lawson__, Asst. Engineer, E. S. Lincoln, Inc., 534 Congress St., Portland, Me.

Chase, Fred Odell, Electrical Engineer, General Electric Co.; res., 761 North St., Pittsfield, Mass.

Clark, Luther Ingersoll, Manager, Clark Electric & Mfg. Co., 149 Broadway; res., 99 Claremont Ave., New York, N. Y.

Clarke, William Harrison, Chief Draftsman, Canadian General Electric Co.; res., 126 Medland St., Toronto, Ont., Canada.

*__Clay, Noble S.__, Research Div., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 1431 Cresson St., Wilkinsburg, Pa.

*__Cohen, Samuel__, Radio Engineer, Wireless Improvement Co., New York; res., 281 Wyona St., Brooklyn, N. Y.

Consler, Walter Joseph, Superintendent, Elec. Meter & Arc Lamp Dept., Rochester Railway and Light Co.,34 Clinton Ave. N., Rochester, N. Y.

Cooper, Charlie Berresford, District Manager, Kilbourne & Clark Mfg. Co., 149 Broadway, New York, N. Y.

Cordell, Philip Marvin, Supt., Meter Dept., Choctaw Power and Light Co., McAlester, Okla.

Cornell, Frederick James, Foreman, Electric Motor Test Dept., General Electric Co., W. Lynn; res., 57 True St., Revere, Mass.

Daunais, Edgar H., Electrical Engineer, American Brass Co.; res., 64 Laurel St., Waterbury, Conn.

Deale, Robert Corey, Ensign, U. S. S. Huntington; res., Babylon, N. Y.

Demorest, Irving R., Foreman, Small Armature Repair Shop, American Car & Foundry Co.; res., 138 Montgomery Ave., Detroit, Mich.

Dewey, Earl Lawrence, Repair & Construction Dept., Pacific Gas & Electric Co.; res., 3412 Geary St., San Francisco, Cal.

Dexter, Merton B., Asst. Supt., Meter Dept., United Electric Light Company; res., 43 Rochelle St., Springfield, Mass.

*__Dickey, D. Adam__, Research Engineering, Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

*__Donnell, Philip S.__, 1st Lieut., Signal Corps, U. S. A., Co. "C" 221st F. S. B., Camp Alfred Vail, Little Silver, N. J.

*__Dow, William__, 1st Lieutenant, Engineers, U. S. Army, Princeton, New Jersey.

Drake, Charles Henry, Asst. Div. Traffic Engineer, Western Union Telegraph Co.; res., 4009 Kenmore St., Chicago, Ill.

*__Duff, Charles Kent__, Research Assistant, Dept. of Electrical Engineering, Univ. of Toronto; res., 102 St. Vincent St., Toronto, Ont., Canada.

*__Eckley, Winfield__, Testing Dept., General Electric Co., Schenectady, N. Y.; res., 76 Parker St., Pittsfield, Mass.

*__Ellefson, Selmer__, Testing Dept., General Electric Co.; res., 231 Union St., Schenectady, N. Y.

Engelhardt, Herman Louis, Valuation Electrical Inspector, Southern Pacific O. A. & B. Electric Lines, San Francisco; res., 455 Vernon St., Oakland, Cal.

Faris, David D., Asst. Manager, Marine Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Finley, Jay Charles, Local Manager, New York Telephone Co., 170 Stone St.; res., 428 Washington St., Watertown, N. Y.

***Fitchen, John Henry**, Electrical Draftsman, New York Navy Yard, Brooklyn; res., 262 W. 31st St., New York, N. Y.

Foley, John H., Commercial Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Forbes, Howard C., Secretary, Welding Committee, Emergency Fleet Corp., U. S. Shipping Board, 33 W. 39th St., New York, N. Y.

***Ford, Frank Reginald**, Station Construction Dept., Philadelphia Electric Co., Philadelphia, Pa.; res., Mickleton, N. J.

***Fox, Louis Rodman**, 2nd Lieutenant, Air Service, U. S. Army; res., 336 Reeder St., Easton, Pa.

Freed, Joseph David, Radio Test Shop, U. S. Navy Yard, Washington, D. C.; res., 434 E. 141st St., New York, N. Y.

Freyeisen, Rudolf H., Asst. Electrical Engineer, L. K. Comstock & Co., 21 East 40th St., New York, N. Y.

Frick, Charles Wilson, Consulting Engineering Laboratory, General Electric Co.; res., 105 Seward Place, Schenectady, N. Y.

***Gallaher, Harold T.**, Master Mechanic, Union Malleable Iron Co., E. Moline; res., 2000 7th Ave., Moline, Ill.

***George, Clifford H.**, Electrical Engineer, Puget Sound Traction, Light and Power Co.; res., 1012½ North 9th St., Tacoma, Wash.

***Goldhammer, Max H.**, Commercial Electrical Engineer, General Electric Co., 1026 Monadnock Bldg.; res., 4621 Sheridan Rd., Chicago, Ill.

Graham, Frank Orrin, Detroit Shell Co.; res., 520-25th St., Detroit, Mich.

Grugel, Herbert William, Telephone Equipment Engineer, Automatic Electric Co.; res., 4212 W. 21st Place, Chicago, Ill.

***Haig, Alfred Leslie**, 2nd Lieutenant, Infantry, U. S. Army; res., 1220 S. 53rd St., Philadelphia, Pa.

***Hall, Horton Warner**, Laboratory Assistant, Experimental Laboratory, General Electric Co., West Lynn, Mass.

***Hall, James Doyle**, Mechanical & Electrical Inspector, The Panama Canal; res., 1213 E. Capitol St., Washington, D. C.

Hamer, Fred C., Electrical Draftsman, Sargent & Lundy, 72 W. Adams St.; res., 1107 N. Dearborn St., Chicago, Ill.

***Haselton, Merton Luther**, Captain, Coast Artillery Corps, U. S. Army, Fort Totten, N. Y.

Henriques, Jacob C., Asst. to Chief Inspector, U. S. Government Explosives Plant, "C", 16 E. 42nd St., New York; res., 1793 West 9th St., Brooklyn, N. Y.

Hetznecker, William Henry, Jr., Apparatus Salesman, Rochester Electric Supply. Co., 90 Main St., Bradford; res., 123 Haines St., Kane, Pa.

***Hoerath, Julius J.**, Asst. Foreman, Turbine Testing Section, General Electric Company, Schenectady, N.Y.

Holcomb, Robert D., Supt., Electrical Construction & Operation, American International Shipbuilding Corp., Hog Island, Pa.

Hood, Clyde, Inspector, U. S. Navy, 938 Edison Bldg.; res., 2110 Prairie Ave., Chicago, Ill.

Horning, Harry H., Electrical Engineer, Cutler-Hammer Mfg. Co.; res., 493 20th Ave., Milwaukee, Wis.

Howard, John Gardner, Engineer, Electrical Dept., The Koppers Co.; res., 5513 Phillips Ave., Pittsburgh, Pa.

Hughes, Richard James, Sales Engineer, Westinghouse Elec. & Mfg. Co.; res., 1537 East 32nd St., Minneapolis, Minn.

***Huntington, Maurice Burt**, Asst. Engineer, Rochester Railway & Light Co.; res., 121 North Fitzhugh St., Rochester, N. Y.

Johnson, Alek, Elec. Tester, Transit Development Co.; res., 828, 49th St., Brooklyn, N. Y.

Johnson, Alvin W., Electrical Engineer, General Electric Co., Chicago; res., 544 Sherman Ave., Evanston, Ill.

*__Johnson, Emroy Theodore__, Switchboard Engg. Div., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., Westinghouse Club, Wilkinsburg, Pa.

*__Junken, Lawrence Howland__, Pittsboro, Indiana.

*__Keller, Frederick Rowe__, Instructor in Electrical Engineering, Columbia University; res., 105 Manhattan Ave., New York, N. Y.

Kellogg, Charles Wetmore, Manager, Mississippi River Power Co.; res., 633 Grand Ave., Keokuk, Iowa.

Kennedy, Jefferson Byron, Electrical Draftsman, G. M. Standifer Construction Corp., Vancouver, Wash.; res., 584 E. 9th St., Portland, Ore.

King, Frank C., Manager, Export Department, Stromberg-Carlson Tel. Mfg. Co.; res., 409 Normandie Apts., Rochester, N. Y.

Kirke, Wallace Bryant, Consulting Engg. Dept., General Electric Co.; res., 217 Seward Place, Schenectady, N. Y.

*__Kneale, Ralph Martin__, Corporal, Signal Corps, U. S. A.; res., 3121 Berkshire Road, Cleveland Heights, Ohio.

*__Kniskern, Floyd B.__, Edgineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 309 Barnes St., Wilkinsburg, Pa.

Knowles, Leonard, Cedar Rapids Power Plant; res., Club House, Cedar, Quebec.

*__Koch, James Richard__, Draftsman, Electrical Dept., Cambria Steel Co.; res., 414 Locust St., Johnstown, Pa.

Koelbel, Frank Delany, Application Engineer, Westinghouse Elec. & Mfg. Co., 1205 Dime Bank Bldg., Detroit, Mich.

Kramer, Russell Stewart, Power Equipment Engineer, Bell Tel. Co. of Pa., 1230 Arch Street, Philadelphia, Pa.

*__Krotzer, J. Earl__, 2nd Lieut. Engineers, U. S. A.; res., 7591 Kelly St., Pittsburgh, Pa.

*__Kusner, Louis__, Electrical Draughtsman, Philadelphia Electric Co.; res., 213 So. 53rd St., Philadelphia, Pa.

Landers, Frank C., Asst. Supt., Western Div., Niagara, Lockport & Ontario Power Co.; res., 8 Beverly Ave., Lockport, N. Y

*__Landman, Sebastian Joseph__, Electrician, Mississippi River Power Co.; res., 1417 Ridge St., Keokuk, Iowa.

Lang, Eugene C., Engineer, The Arnold Company; res., 3623 Pine Grove Avenue, Chicago, Ill.

*__Lang, Louis Arthur__, Electrician, Portland Railway, Light & Power Co.; res., 949 Commercial St., Portland, Ore.

Larson, David C., Engineer, Otis Elevator Co., 250-11th Avenue, New York; res., 112 Elliott Ave., Yonkers, N. Y.

*__Laurer, George A., Jr.__, Electrical Draftsman, Machinery Div., Brooklyn Navy Yard, New York; res., 600 Park Ave., Syracuse, N. Y.

*__Leech, Vernon Everett__, Laboratory Instructor & Student, Univ. of Southern California; res., 1170 W. 37th Place, Los Angeles, Cal.

*__Leeds, Josiah Lippincott__, Electrical Draftsman, Pusey & Jones Company, Gloucester; res., 257 E. 3rd Street, Moorestown, N. J.

Lindeman, Joseph, Construction & Operating Depts., Metropolitan St. Rys. Co., N. Y. Rys. Co., & Interborough Rapid Transit Co., New York, N. Y.

*__Line, John Donald__, Process Foreman, Insulating Dept., Westinghouse Elec. & Mfg. Co., 609 Ecker Way, Wilkinsburg, Pa.

Lloyd, John H., Electrical Engineer, Government of Panama, Panama, R. P.

Loomis, Emery W., Westinghouse Elec. & Mfg. Co., 165 Broadway, New York, N. Y.; res., 85 Berwyn St., Orange, N. J.

*Lu, Cheng-Chih, Electrical Engineer, Packard Electric Co.; res., 306 E. Atlantic St., Warren, Ohio.

Lusk, Ward W., 2nd Lieut., Engineering Div., Ordnance Dept., U. S. A., Washington, D. C.; res., 839 N. Center St., Reno, Nevada.

Mansfield, Ralph G., Electrical Engineer, Union Carbide Co., Niagara Falls; res., La Salle, N. Y.

Mason, Karl Carson, Asst. Elec. Engineer, Edison Elec. Ill. Co. of Brockton, 76 School St., Brockton; res., E. Bridgewater, Mass.

Massel, Julian S., Electrician, National City Bank, 55 Wall St., New York; res., 149 Ridgewood Avenue, Brooklyn, N. Y.

*Maxstadt, Francis William, Asst. Engineer, Interborough Rapid Transit Co., 621 Broadway, New York, N. Y.; res., 170 William St., Newark, N. J.

McCabe, George Curtin, Electrical Inspector, Navy Yard; res., 1378 E. Capitol St., Washington, D. C.

McCanne, W. Roy, Treasurer and Gen. Manager, Stromberg-Carlson Telephone Mfg. Co.; res., 225 Barrington St., Rochester, N. Y.

McGill, C. S., Supervising Electrician, The Foundation Co.; res., 1033 Lincoln St., Portland, Ore.

McGown, Dudley Brooke, Asst. U. S. Naval Radio Inspector, 435 Mission Street, San Francisco, Cal.

McVittie, F., Electrical Engineer, New York State Railways, 267 State St., Rochester, N. Y.

Meeker, Arthur Manning, Engineering Dept., Public Service Electric Co.; res., 196 North 3rd St., Newark, N. J.

*Melby, Einar C., Manager, Machinery Equipment & Supply Dept., Harper, Marshall & Thompson Co., Inc.; res., 520 W. 129th St., New York, N. Y.

Mell, Frederick, Electrical Foreman, Westinghouse, Church, Kerr & Co., New York, N. Y.; res., 63 Tonnelle Ave., Jersey City, N. J.

*Mellen, Earl Rufus, Correspondent Engineer, Weston Electrical Instrument Co., Waverley Park; res., 32 Treacy Ave., Newark, N. J.

*Menke, O. H., Habart Bros. Co.; res., 23 South Mulberry St., Troy, Ohio.

Meyer, David, Second Switchboard Man, Interborough Rapid Transit Co.; res., 730 East 182nd St., New York, N. Y.

*Meyer, Grover C., Industrial Engineer, Kansas City Light & Power Co.; res., 3940 Broadway, Kansas City, Mo.

*Meyer, Harry Pendleton, General Electric Co.; res., 5 Henry Street, Schenectady, N. Y.

*Mickey, Bruce D., Student Engr., Testing Dept., General Electric Co.; res., 104 S. Jay St., Schenectady, N.Y.

*Miller, Clarence E., Asst. Equipment Engineer (Telephone), Central Union Telephone Co.; res., 1725 Wilson Ave., Chicago, Ill.

Miller, Edward John, Electrical Foreman. Westinghouse, Church, Kerr & Co. Inc., New York; res., 1601 Moltke Ave., Scranton, Pa.

*Miller, Herman Potts, Jr., Electrical Engineer, Federal Telegraph Co., 400 Homer Bldg., Washington, D. C.

Mills, Ralph Harold, Electrical Engineer, Western Electric Co., 463 West St., New York, N. Y.; res., 12 Byron Ave., Natick, Mass.

Mishler, E. W., New York Shipbuilding Corp.; res., 319 North 2nd St., Camden, N. J.

*Monroe, Wendell Potter, Student Engineer, General Electric Co.; res., 710 South Ave., Schenectady, N. Y.

Morton, Albert B., Manager, Rome Gas, Electric Light and Power Company, 139 N. James St., Rome, N. Y.

Moses, William H., 7 Joe St., Niagara Falls, Ontario, Can.

Moulton, Orin Lawrence, Supt., Interior Lighting & Power Construction, Cheyenne Light, Fuel & Power Co.; res., 217 E. 20th St., Cheyenne, Wyo.

*__Moyer, Howard Rollin__, Engineering Assistant, Transmission Engg. Dept., The Bell Telephone Co., Pittsburgh; res., 1425 Cresson St., Wilkinsburg, Pa.

Murphy, Albert J. J., Senior Inside Man, N. Y. Telephone Co., 15 Dey St., New York; res., 7504 Sixth Ave., Brooklyn, N. Y.

*__O'Daniel, Clarence__, Industrial Engineer, Century Electric Co., 506 Rockefeller Bldg., Cleveland, Ohio.

*__Oswald, Arthur A.__, Radio Research Laboratory, Western Electric Co., New York; res., 174 N. Grove St., E. Orange, N. J.

Otaka, Tokuju, Engineer, Oana Elec. & Mfg. Co., Tamahime-cho, Asakusa, Tokyo, Japan.

Palmer, Jacob Long, General Electrical Foreman, Westinghouse, Church, Kerr & Co., Inc., 37 Wall St., New York, N. Y.; res., Keezletown, Va.

Parker, Heckert L., Vice-President & Secretary, Conneaut Metal Works Co.; res., 374 Liberty St., Conneaut, Ohio.

*__Perry, Gardner Darling__, Telephone Equipment Man, American Tel. & Tel. Company; res., 786 Third Avenue, North Troy, N. Y.

*__Peterson, Elmer Gustav__, Engineering Dept., The Cutler-Hammer Mfg. Co.; res., 1321 Cedar St., Milwaukee, Wis.

*__Piercy, Carl Albert__, Engineer, Wire & Cable Dept., General Electric Company; res., 523 Rugby Road, Schenectady, N. Y.

Pierson, Raymond Townsend, Sales Engineer, Stromberg-Carlson Tel. Mfg. Co.; res., 271 University Avenue, Rochester, N. Y.

*__Poole, Fred L.__, Consulting Engineering Dept., General Electric Co.; res., 203 Seward Place, Schenectady, N. Y.

Pope, Floyd Raymond,, District Manager, Century Electric Company, 1017 Bessemer Bldg.; res., 904 Peebles Street, Pittsburgh, Pa.

Popkin, Martin E., Department of Labor, 469 Fifth Ave.; res., 600 W. 187th St., New York, N.Y.

*__Price, George Francois__, Engineering Dept., Peet & Powers, 70 E. 45th St.; res., 18 West 30thSt.,New York, N.Y.

Putman, Omer E., Electrical Cable System Operation, Interborough Rapid Transit Co., 621 Broadway, New York, N. Y.

*__Putnam, Ralph E. A.__, Engineering Department, Western Electric Company; res., 53 Manhattan Avenue, New York, N. Y.

Ray, Arthur William, Acting Chief Engineer, Reliance Electric and Engineering Co.; res., 14607 Orinoco Ave., E. Cleveland, Ohio.

Reese, Claude Earnest, Assistant Engineer, Illinois Public Utilities Comm.; res., 846 S. Douglas Street, Springfield, Ill.

*__Renfro, Charles Harold__, 1st Lieut. of Engineers, U. S. A.; res., 1428 Columbia Road, N. W., Washington, D. C.

Reynolds, Chester H., Electrical Engineer, Supervising Architect's Office, Treasury Bldg.; res., 212, 7th St. S. W., Washington, D. C.

*__Reynolds, Harold Vernan__, Load Dispatcher, San Joaquin Light & Power Corp.; res., 3740 Iowa Ave., Fresno, Cal.

*__Reynolds, John Paul__, Load Dispatcher, West Penn Power Co., Pittsburgh; res., 110 Atlantic Ave., McKeesport, Pa.

*__Rhoads, Charles Stanley, Jr.__, Regional Tel. & Tel. Engineer, U. S. R. R. Administration, Grand Central Terminal, New York, N. Y.

*__Richardson, Chester Northup__, 2nd Lieut., Chemical Warfare Service, U. S. A.; res., 2709 Wisconsin Ave., Washington, D. C.

Roeser, Edward A., Industrial Engineer, Rochester Railway & Light Co., 34 N. Clinton Ave., Rochester, N. Y.

*__Sakuma, Fumiya__, Supervisor of Electrical Work, Nielsen & Kittle Canning Co., Ltd., Terminal, Cal.

Sampson, Clarence Newton, Sales Dept., U. S. Steel Products Co.; res., 45 Rose Friend Apts., Portland, Ore.

Sanderson, David G. P., Charge Engineer, Hydro-Electric Plant, Dryden Pulp & Paper Mills; res., Duke St., Dryden, Ont.

***Sarvas, Otto**, Owner, Efficient Service Co., 220 W. 42nd St.; res., 721 E. 166th St., New York, N. Y.

Schlick, Frank Lewis, Chief Inspector, Shepard Electric Crane & Hoist Co., Montour Falls, N. Y.

Schmitt, Rudolph F., Asst. Engineer, Cleveland Elec. Ill. Co.; res., 1845 E. 75th St., Cleveland, Ohio.

Shaw, Archibald Livingston, Purchasing Dept., Splitdorf Electric Co.; res., No. 1 Alpine St., Newark, N. J.

Sherwin, Arthur J., Inspector, Interborough Rapid Transit Co., 621 Broadway; res., 515 W. 143rd St., New York, N. Y.

***Siefert, Paul H.**, Electrical Engineer, Industrial Controller Co.; res., 644 Jefferson St., Milwaukee, Wis.

Skinner, Don Reynolds, Asst. Chief Operator, Western Union Tel. Co.; res., 5415 W. Ohio St., Chicago, Ill.

Skinner, Stanley I., Plant Engineer, Kansas City Home Tel. Co., 800 Orear-Leslie Bldg., Kansas City, Mo.

Skone, Robert Conrad, Foreman of Inside Constructors, City Light Steam Plant, Eastlake & Nelson Place, Seattle, Wash.

***Skutecki, Joseph W.**, Designer, The B. F. Goodrich Co.; res., 174 W. Chestnut St., Akron, Ohio.

Slocum, Hiram Ray, Foreman, Switchboard Dept., Sperry Gyroscope Co.; res., 145 Powers St., Brooklyn, N. Y.

Smith, John A., Electrical Engineer: National Electric Co., Christchurch, res., 20 Crohane St., Addington, N. Z.

***Smith, Walter Robert**, Erecting Engineer, Canadian Westinghouse Co., 24 Canada Life Bldg., Calgary, Alta, Canada.

Snedeker, Clarence Felter, Motive Power Dept., Interborough Rapid Transit Company, New York; res., 67 Beechwood Avenue, Bogota, N. J.

Sprado, Hugh Randolph, 1st Lieut., Signal Corps, U. S. A., Department Signal Office, Fort Sam Houston, Texas.

***Steinmayer, Alvin Gustave**, Private, U. S. A., Government Chemical Plant No. 4, Saltville, Va.; res., La Salle, Ill.

***Steven, Harry Misener**, Student Engineer, General Electric Co.; res., 45 Front St., Schenectady, N. Y.

Stinson, William L., 230 Liberty St., Schenectady, N. Y.

***Stone, Harry E.**, Engineer, Service Dept., West Penn Power Co., Pittsburgh; res., 405 Biddle Ave., Wilkinsburg, Pa.

***Stoos, Frank Albert**, Construction Foreman, Engg. Dept., General Electric Co.; res., Y. M. C. A., Cincinnati, Ohio.

Sugden, Henry, Engineer, Roller-Smith Company; res., 23 S. 10th Avenue, Bethlehem, Pa.

Sutherland, Harry Thomas, Jr., Asst. to Engineer, Lewis H. Woods Construction Co., 2355 Jerome Ave., New York; res., Woodhaven, N. Y.

***Swett, Lewis Wentworth**, Technical Correspondent, Domestic Engineering Co.; res., No. 3 Normandie Apts., Dayton, Ohio.

***Sykes, Clifford B.**, Lighting Dept., General Electric Co.; res., 303 Parkwood Blvd., Schenectady, N. Y.

***Thomas, Beverly, Jr.**, Asst. Electrical Engineer, Westinghouse, Church, Kerr & Company, 37 Wall St.; res., 92 Grove St., New York, N. Y.

Thomas, Herman, Chief Electrician, Electrical Dept., American Manganese Steel Co.; res., 148 East 4th St., New Castle, Del.

Thomas, Howard Waring, Bureau of Steam Engineering, Navy Dept.; res., 717 10th St., N. W., Washington, D.C.

***Tompkins, Eugene Randolph**, 566 Ninth Ave., S. W., Roanoke, Va.

***Trevor, Karl Robert**, Thomas Morse Aircraft Corp.; res., 4 The Circle, Ithaca, N. Y.

Vernon, William Somerville, Lecturer of Physics, University College, Auckland, N. Z.

Wagner, Arthur J., Assistant Manager, Recorder Department, Taylor Instrument Company; res., 85 Seneca Parkway, Rochester, N. Y.

Wantz, J. B., Vice-President, Victor Electric Corp., 236 South Robey St., Chicago; res., Oak Park, Ill.

***Warner, Russell Gillette**, Instructor in Elec. Engg., Sheffield Scientific School; res., 350 Yale Ave., New Haven, Conn.

Waters, Frederick Elmer, Construction Inspector, Bell Telephone Co. of Pa.; res., 5219 Pine St., Philadelphia, Pa.

***Weppler, Harvey Stanley**, Meter Inspector, The Hydro-Electric Power Comm. of Ontario, Toronto; res., Hanover, Ontario, Canada.

***White, William R.**, Electrical Engineer, Philadelphia Electric Co.; res., 406 West Chelton Ave., Philadelphia, Pa.

Whitney, Charles A., Engineer, National Board of Fire Underwriters, 76 William St., New York, N. Y.

***Williams, Raymond Cabot**, Construction Foreman, General Electric Co., Philadelphia; res., 355 Bridge St., Spring City, Pa.

Williams, William Allyn, Motor Test Dept., General Electric Co.; res., 1 Classical Terrace, Lynn, Mass.

***Williamson, Claude A.**, Engineer, Mechanical & Electrical Dept., Youngstown Sheet & Tube Co., 1744 South Heights Ave., Youngstown, Ohio.

Winterer, Horace Kenneth, Commercial Engineer, General Electric Co.; res., 1411 Arthur Ave., Chicago, Ill.

***Wood, Winthrop Chace**, Industrial Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.; res., 145 Osborn Street, Fall River, Mass.

Wronker, Ralph, Private, Signal Corps, U. S. Army; res., 5240 Indiana Ave., Chicago, Ill.

***Youtz, J. Paul**, Direct Current Engineering, General Electric Co.; res., 203 Seward Place, Schenectady, N. Y.

*Former enrolled Students

Total 212

ASSOCIATES REELECTED FEBRUARY 19, 1919

Cooper, Leo. H., District Manager, Frank Adam Electric Co., 200 Builders Exchange, Minneapolis, Minn.

Dubilier, William, Consulting Engineer, 217 Center St.; res., 124 West 72nd St., New York, N. Y.

Ferrey, Fred G., Turners Falls Power and Electric Co., Greenfield, Mass.

Flansburg, P. LeRoy, Safety & Efficiency Engineer, E. I. du Pont de Nemours & Co., Haskell, N. J.

Merrill, Josiah Leverett, Public Utilities Comm. of Ohio; res., 459 6th Ave., Columbus, Ohio.

Platt, Frederick, Mechanical & Shop Engineer, General Electric Co., W. Lynn; res., 37 Mt. Vernon St., Cliftondale, Mass.

Stevens, Henry R., Electrical Engineer, Stone & Webster, 868 Stuart Bldg., Seattle, Wash.

MEMBERS ELECTED FEBRUARY 19, 1919

Butler, Earnest L., Supt. of Light & Water Department, 306 N. Pine St.; res., Antlers Hotel, Ellensburg, Wash.

Carr, Walter R., Editor, *Electrical News*, 347 Adelaide St. W.; res., 289 Inglewood Drive, Toronto, Ont., Canada.

Iler, George Arthur, Supt. of Operation, Georgia Railway & Power Co.; res., 311 W. Peachtree St., Atlanta, Ga.

McInnerney, Benjamin, Vice-Pres. & Manager, Kimball Bros. Company; res., 208 Tenth Ave., Council Bluffs, Iowa.

Roberts, William, Manager, Callenders Cable & Construction Co. Ltd., Killick Bldg.; res., Pedder Road, Cunballa Hill, Bombay, India.

Rudd, Frederick Jett, Electrical Engineer, General Electric Co., W. Lynn; res., 312 Humphrey St., Swampscott, Mass.

Semrad, C. A., General Manager, The Western Light & Power Co.; res., 537 Pine St., Boulder, Colo.

Tappan, Frank Girard, Acting Director of School of Elec. Engg., Supervisor of Vocational Training, Univ. of Oklahoma, Norman, Okla.

Yarnall, Joseph Henry, Asst. Engineer, Elec. Engg., Dept., Boston Elevated Railway Co., Boston; res., 55 Dakota St., Dorchester, Mass.

TRANSFERRED TO THE GRADE OF FELLOW FEBRUARY 19, 1919

Magalhaes, Frank V., Superintendent of Test Dept., N. Y. Edison Co., New York, N. Y.

Wyman, Walter Scott, Treasurer & General Manager, Central Maine Power Co., General Manager, Adirondack Electric Power Corp., Augusta, Me.

TRANSFERRED TO THE GRADE OF MEMBER FEBRUARY 19, 1919

Berger, Julius G., Chief Engineer, Wm. Gordon Corp., Philadelphia, Pa.

Clarke, H. O., Jr., Captain, Quartermaster Corps, Construction Div., Camp Logan, Tex.

Harden, William H., Engineering Dept., American Telephone & Telegraph Co., New York, N. Y.

Lustig, Leo, Electrical and Mechanical Engineer, Ciego de Avila Water Supply & Electric Corp., Ciego de Avila, Cuba.

Sakai, Yasudiro, Chief Engineer, Yasukawa Electric Mfg. Co., Kuro-Fsaki, ukuoka-ken, Japan.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its regular monthly meeting held on February 19, 1919, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

Addicks, Lawrence, Consulting Engineer, New York, N. Y.

To Grade of Member

Cooper, Leo H., District Manager, Frank Adam Electric Co., Minneapolis, Minn.

Langworthy, R. A., Engineer, Stone & Webster, Boston, Mass.

Pratt, Harlan A., Manager, Industrial Division, Westinghouse Electric & Mfg. Co., New York, N. Y.

Rice, Martin P., Electrical Engineer, General Electric Co., Schenectady, N. Y.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before March 31, 1919.

Adams, Q., (Member), Washington, D. C.
Aik, E. H., Milwaukee, Wis.
Alden, F. N., Fort Sam Houston, Texas
Allen, E. S., Brooklyn, N. Y.
Alexander, C. F., New York, N. Y.
Alexander, D. M., Spokane, Wash.
Ammen, J. N., Washington, D. C.
Angel, C. W., New York, N. Y.
Baerresen, A. W., Denver, Colo.
Banan, H. F., E. Pittsburgh, Pa.
Baring, J. W., Chicago, Ill.

Barnett, D. A., Muscle Shoals, Ala.
Baunach, R. P., Jr., New York, N. Y.
Beckmann, J. E., San Francisco, Cal.
Bellerjeau, W. Y., New York, N. Y.
Bennington, E. T., Cleveland, Ohio.
Berkshire, W. T., Schenectady, N. Y.
Bertolacci, R. L., San Francisco, Cal.
Blattner, D. C., New York, N. Y.
Blumer, C. A., E. Pittsburgh, Pa.
Blythe, F. W., Toronto, Ont.
Bohe, C. P., St. Louis, Mo.
Brennan, J. A., Jersey City, N. J.
Brockman, C., Bay City, Mich.
Bronson, C. D., Oakland, Cal.
Bullerjahu, A. D., Milwaukee, Wis.
Bumbaugh, H. L., Corvallis, Ore.
Bunyan, R. P., Brooklyn, N. Y.
Bowness, F., Peterboro, Ont.
Call, G. R., Sioux City, Iowa.
Callahan, W. E., (Member), Cambridge,
Campbell, T. C., New York, N. Y.
Ohio.
Carfield, R. J., Garfield, Utah.
Carrano, G. J., New York, N. Y.
Carroll, A. A., Pueblo, Colo.
Cherry, F. H., Berkeley, Cal.
Chessin, I. I., Brooklyn, N. Y.
Chin, J. K., Wilkinsburg, Pa.
Clark, H. W., Salt Lake City, Utah.
Comstock, H., (Member), Mineville, N. Y.
Condgen, W. E., Washington, D. C.
Cook, R. H., New York, N. Y.
Coutant, G. C., Brooklyn, N. Y.
Cowgill, M. R., Camden, N. J.
Cozine, J. P., New York, N. Y.
Crabbe, W. J., Stanislaus, Cal.
Crittenden, E. C., Washington, D. C.
Cross, C. M., Pittsburgh, Pa.
Dart, W. A., Potsdam, N. Y.
Darrow, K. K., New York, N. Y.
Day, C. M., Denver, Colo.
Demuth, A. A., Brooklyn, N. Y.
Diebold, P. J., Salt Lake City, Utah.
Doane, G. J., Ottawa, Ont.
Dodds, J. M., Washington, D. C.
Doi, K., New York, N. Y.
Dorwin, O. J., New York, N. Y.
Dudrey, H. E. A., (Member), Cincinnati, Ohio.
Dyer, A. C., Pittsburgh, Pa.
Eastham, M. E., Cambridge, Mass.
Egner, R. J., Philadelphia, Pa.
Elliott, T. K., Jr., New York, N. Y.
Emery, R. C., Boston, Mass.
Endicott, T. H., Indianapolis, Ind.
Evans, P. W., New Haven, Conn.
Ewing, C., New York, N. Y.
Falter, P. H., (Member), Baltimore, Md.
Farmer, P. M., (Member), Newark,
Fellows, W. H., Washington, D. C.
N. J.
Fisher, N. I., Toronto, Ont.
Flanders, C. K., New York, N. Y.
Frantz, L. T., (Member), New Orleans, La.
Frost, C. A., Pittsburgh, Pa.
Gearhart, J. H., New York, N. Y.
Giannini, P. H., San Francisco, Cal.
Gibson, A. C., New York, N. Y.
Goodwin, P. R., New York, N. Y.
Grace, J. G., E. Pittsburgh, Pa.
Grant, H. L., New York, N. Y.
Hadlock, H. W., Boston, Mass.
Hafemeister, F. F., Cleveland, Ohio.
Halburton, W. H., Montreal, P. Q.
Hallatt, S. L., Toronto, Ont.
Hamer, W. D., Indianapolis, Ind.
Haney, G. W., Youngstown, Ohio.
Hanley, N. F., Pittsfield, Mass.
Hansson, E., Baltimore, Md.
Harrington, W. C., Cleveland, Ohio.
Harrsen, H., New York, N. Y.
Hauser, G. H., Garden City, L. I.
Hayes, S. E., Detroit, Mich.
Heays, G. L., Kearny, N. J.
Herwegh, L. J., Philadelphia, Pa.
Higbie, W. S., New York, N. Y.
Higgins, N. B., Baltimore, Md.
Hodgson, W. D., (Member), Evanston, Ill.
Hoffman, G. L., Minidoka, Idaho.
Hohs, E. G., Toronto, Ont.
Hoke, W. W., New York, N. Y.
Holcombe, E. S., New York, N. Y.
Holler, H. D., Washington, D. C.
Holliday, S. H., E. Pittsburgh, Pa.
Holslag, C. J., (Member), Newark, N. J.
Hookway, C. W., Toronto, Ont.
Hooven, M. D., Turtle Creek, Pa.
Hopes, A. J., Kearny, N. J.
Hopper, C. H., Toronto, Ont.
Houck, R. S., New York, N. Y.
Houston, A. J., Barton, Tioga Co., N.Y.
Howe, J. A., Rochester, N. Y.
Hsieh, Z., E. Pittsburgh, Pa.

Hughes, G. N., (Member), Maryville, Tenn.
Hunter, H. E., Toronto, Ont.
Iddings, F. T., Baltimore, Md.
Ikola, E., Pittsburgh, Pa.
Insull, F. W., Tulsa, Okla.
Ivanchenko, A. I., Baltimore, Md.
James, W. S., E. Potomac Park, D. C.
Janvrin, E. B., Washington, D. C.
Jardine, A. D., Windson, Ont.
Jennings, P. D., Seattle, Wash.
Johnson, A., Denver, Colo.
Johnson, H. S., New York, N. Y.
Jones, T. McD., W. Allis, Wis.
Kalantar, H. H., New York, N. Y.
Kelly, H. S., New York, N. Y.
Kern, J. G., New York, N. Y.
Kerschner, E., Washington, D. C.
Koch, F. E., San Francisco, Cal.
Koshinsky, J. F., Greenfield, Mass.
Lamphier, B. R., New York, N. Y.
Langille, W., Jersey City, N. J.
Leeming, H. H., Toronto, Ont.
Leet, H. L., Binghamton, N. Y.
Lewis, L. E., Muscle Shoals, Ala.
Lindridge, C. D., New York, N. Y.
Lintern, W. M., Cleveland, Ohio.
Lipps, W. L., Toledo, Ohio.
Lovell, T. J., Denver, Colo.
Macfarlane, J. C., Toronto, Ont.
Marchant, L., Woodbury, N. J.
Marscheider, W. H. E., New York, N.Y.
Marino, R., New York, N. Y.
Martin, J. C., Toronto, Ont.
Marting, H. E., New York, N. Y.
Mathers, H. J., New York, N. Y.
Maynard, H. V., Toronto, Ont.
McGloin, W. J., New York, N. Y.
Middleton, G. N., Toronto, Ont.
Milbyer, J. H., Syracuse, N. Y.
Miller, C. A., New York, N. Y.
Miller, H. E., Springfield, Ohio.
Miller, J. W., Toronto, Ont.
Miller, M. W., Philadelphia, Pa.
Mitchell, L. C., (Member), Washington, D. C.
Montgomery, C. A., San Francisco, Cal.
Moran, I. H., Washington, D. C.
Morgan, A. W., Denver, Colo.
Mullikin, C. A., Pittsburgh, Pa.
Musen, O., New York, N. Y.
Nelson, J. D., Cleveland, Ohio.
Newton, F. L., Washington, D. C.
Niesse, J. L., Indianapolis, Ind.
Olney, W. M., Brooklyn, N. Y.
Packman, W., Toronto, Ont.
Painter, F., Detroit, Mich.
Papadopoulos, J., Camp Merritt, N. J.
Patterson, R. R., Washington, D. C.
Peters, E. L., Bluefield, W. Va.
Philip, G. O., Niagara Falls, Ont.
Phillips, A. J., Toronto, Ont.
Phillips, J., Chicago, Ill.
Pierce, R. T., E. Pittsburgh, Pa.
Plumb, H. H., Denver, Colo.
Price, J. M., Wilmington, Del.
Quimby, R. B., Schenectady, N. Y.
Rawlings, J. B., Washington, D. C.
Reed, K. A., New York, N. Y.
Reiner, M., Baltimore, Md.
Riddell, W., New York, N. Y.
Rodgers, E. H., Jr., Mt. Vernon, N. Y.
Roeder, C. H., Washington, D. C.
Rogalinski, W. A., New York, N. Y.
Rogers, A. N., Cleveland, Ohio.
Ross, S. W., Long Island City, N. Y.
Roswell, C. M., Bluefield, W. Va.
Rinker, R. L., Jackson, Mich.
Rue, J. R., Jr., Pittsfield, Mass.
Salzaman, C. F., Washington, D. C.
Sargent, G. F., Boston, Mass.
Sauerborn, N. T., New York, N. Y.
Schnurer, J., New Haven, Conn.
Sellers, H. K., Washington, D. C.
Shakelford, B. E., Bloomfield, N. J.
Sharpe, E. W., Pittsfield, Mass.
Shaw, H. S., Jr., Newton Center, Mass.
Sheldan, M. H., Bedford, Ohio.
Shinn, W. C., Burlington, N. J.
Sibley, E. K., New York, N. Y.
Siess, G. N., Cleveland, Ohio.
Simons, A. G., New York, N. Y.
Smith, C. R., New York, N. Y.
Smith, H. H., Keokuk, Iowa.
Smith, H. L., Schenectady, N. Y.
Smith, R. A., New York, N. Y.
Smith, T. C., New York, N. Y.
Somers, A. B., New York, N. Y.
Sordelet, C. B., Pueblo, Colo.
Sparr, V. W., Long Island City, N. Y.
Stalford, V. K., Toronto, Ont.
Stansfield, A. C., Peterboro, Ont.
Stason, E. B., Hoboken, N. J.
Staubitz, L. P., Chicago, Ill.
Stone, H. D., (Member), New Haven, Conn.

Stone, E. L., Jr., New York, N. Y.
Stetler, F. E., Lewisburg, Pa.
Strafford, C. M., Philadelphia, Pa.
Stroessner, F. A., Denver, Colo.
Sullivan, D. E., New York, N. Y.
Swan, W. D., Brooklyn, N. Y.
Tapp, N. P., Cleveland, Ohio.
Tate, A. E., New York, N. Y.
Taylor, H. E., Detroit, Mich.
Thomas, G. P., Toronto, Ont.
Thornton, A., Cleveland, Ohio.
Thompson, G. S., E. Pittsburgh, Pa.
Tibbala, E. C., Anatol, N. J.
Tobyn, J. A., Spokane, Wash.
Tresselt, O. H., New York, N. Y.
Tuttle, G. H., Warren, Ohio.
Ulmer, H. T., Detroit, Mich.
Van Deusen, H. N., New York, N. Y.
Voyle, C. C., Gainesville, Fla.
Waldron, C. A., New York, N. Y.
Walker, J. W., Toronto, Ont.
Walker, T. L., Spokane, Wash.
Walsh, R. L., Chicago, Ill.
Walton, B. C., Peekskill, N. Y.
Wanser, L., New York, N. Y.
Watrous, R. C., Cambridge, Mass.
Webster, A. G., (Fellow), Worcester, Mass.
Weed, DeW. V., Jr., New York, N. Y.
Weidman, A. J., Washington, D. C.
Wells, J. A., New York, N. Y.
Wendell, F. T., New York, N. Y.
Whitaker, L. G., New York, N. Y.
White, F. W., Brooklyn, N. Y.
White, W. P., Pittsfield, Mass.
Wickstrom, H. L., Denver, Colo.
Wilkes, A. E., Toronto, Ont.
Willatt, A. F., San Francisco, Cal.
Wilson, H., Muscle Shoals, Ala.
Wilson, J. B., Massillon, Ohio.
Wohlers, F. H. N., New York, N. Y.
Wright, R. K., Philadelphia, Pa.
Wright, L. E., San Francisco, Cal.
Wood, A. P., Schenectady, N. Y.
Wyss, F. C., New York, N. Y.
Zaugg, F. S., Tacoma, Wash.
Zeller, C. J., New York, N. Y.
Zwally, E. J., (Member), Racine, Wis.
Total 259

Foreign Applications

Bekku, S., Tokyo, Japan.
Binns, A. P., Hobart, Tasmania.
Foster, E. G., (Member), Invercargill, N. Z.
Gantvoort, W. F., Soerabaya, Java, D. E. Indies.
Horai, M., Takatsuki, Kyoto fu, Japan
Marriott, C. H., Whaugarei, N. Z.
Mayoral, D., Barcelona, Spain.
Stephens, J. G., Christchurch, N. Z.
Templin, J. R., (Member), Christchurch, N. Z.

Total 9

STUDENTS ENROLLED FEBRUARY 19, 1919

9839 McElwell, J. M., Montana State Coll.
9840 Hoeft, E. W., School of Engg. of Milwaukee.
9841 Collins, C. H., Univ. of Wis.
9842 von Normann, A. G., Univ. of Wash.
9843 Hartman, Zoltan, Cooper Union.
9844 Sheer, Joe Robert, Univ. of Wis.
9845 Hoffman, Andrew J., Tri-State Coll.
9846 Day, John F., Univ. of Penn.
9847 Dickerson, Edwin S., Jr., Drexel Inst.
9848 Cartlett, James T., Univ. of Wash.
9849 St. Clair, Harry P., Throop Coll. of Tech.
9850 Housell, Theron C., Throop Coll. of Tech.
9851 Coops, Herbert S., Throop Coll. of Tech.
9852 Hopper, Francis L., Throop Coll. of Tech.
9853 Glasby, Whitman K., Throop Coll. of Tech.
9854 Duguid, Russell H., Throop Coll. of Tech.
9855 Cory, George L., Throop Coll. of Tech.
9856 Sawyer, Mark A., Throop Coll. of Tech.
9857 Knapp, Robert T., Throop Coll. of Tech.
9858 Smith, Donald D., Throop Coll. of Tech.
9859 Otis, Russell M., Throop Coll. of Tech.

9860 Hounsell, Edward V., Throop Coll. of Tech.
9861 Crosby, Paul N., Throop Coll. of Tech.
9862 De Nunzio, S., N. Y. Elec. School.
9863 Stoker, R. J., West Va. Univ.
9864 McDonald, P. D., West Va. Univ.
9865 Walls, H. J., West Va. Univ.
9866 Fisher, W. C., West Va. Univ.
9867 Lloyd, W. J., Univ. of Wash.
9868 Wensk, J.A., Baltimore Poly.Inst.
9869 Borden, D. C., Toronto Tech. School.
9870 King, T. W., Univ. of Wis.
9871 Anderson, S. E., Univ. of Mich.
9872 Walker, G. H., Univ. of Wash.
9873 Langland, H. S., Univ. of Minn.
9874 Hartman, W. K., Univ. of Minn.
9875 Nelson, C. L., Univ. of Minn.
9876 Knowles, E. H., Univ. of Minn.
9877 Mayer, A. F., Univ. of Minn.
9878 Triem, R. H., Univ. of Minn.
9879 Wilson, P. R., Univ. of Minn.
9880 Hougan, S., Univ. of Minn.
9881 Giegler, A. L., State Coll. of Wash.
9882 Weissman, E., Brooklyn Poly. Tech. Inst.
9883 Edmonds, E. A., Univ. of Ky.
9884 Milton, H. M., Univ. of Ky.
9885 de Mey, V. F., Univ. of Ky.
9886 Singer, F. J., Univ. of Wash.
9887 Becker, M., Cooper Union
9888 Keller, A. C., Cooper Union
9889 Munro, R. A., Univ. of Mich.
9890 Spanagel, E. L., Univ. of Mich.
9891 Friedman, M. D., Univ. of Mich.
9892 Steininger, R. H., Univ. of Mich.
9893 Steinbach, H. L., Univ. of Mich.
9894 Ilgenfritz, L. M., Univ. of Mich.
9895 Goodale, J. C., Univ. of Mich.
9896 Brown, A. E., Univ. of Mich.
9897 Gunn, R., Univ. of Mich.
9898 Ito, T., Univ., of Mich.
9899 Davidson, O. C., Jr., Univ.of Mich.
9900 Schwarz, J. M., Univ. of Mich.
9901 Lynch, J. T., Univ. of Mich.
9902 Palmer, R. J., Univ. of Mich.
9903 Groves, W. E., Univ. of Mich.
9904 Josey, H. I., Univ. of Mich.
9905 White, R. G., Univ. of Mich.
9906 Willson, K. A., Univ. of Mich.
9907 Powers, C. F., Casnno Tech. Night School.
9908 Schwarz, E. E., Cooper Union.
9909 Anderson, A. S., Univ. of Colo.
9910 McGinty, E. A., Univ. of Cal.
9911 Tanner, A. R., Univ. of Cal.
9912 Johnson, A. R., Univ. of Cal.
9913 Emery, W. K., School of Engg. of Milwaukee.
9914 Keller, R., School of Engg. of Milwaukee.
9915 Rohrecker, L. R., Cooper Union.
9916 Sovik, R. A., Tri-State Coll.
9917 Moorman, H. T., Purdue Univ.
9918 Shryock, J. R., Purdue Univ.
9919 Nottingham, W. B., Purdue Univ.
9920 Williams, G. R., Purdue Univ.
9921 Ewbank, E. A., Purdue Univ.
9922 Eiler, C. K., Purdue Univ.
9923 Harris, F. H., Purdue Univ.
9924 Conner, I. L., Purdue Univ.
9925 Brizius, H. W., Purdue Univ.
9926 Lloyd, M., Mass. Inst. of Tech.
9927 Shelton, F. H., Univ. of Mo.
9928 Bibber, H. W., Mass. Inst. of Tech.
9929 Stier, F. E., Lafayette Coll.
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9958 van der Linden, J. C., N. Y. Elec. School.
9959 Stellwagen, G. T., N. Y. Elec. School.
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9966 Baumer, H. W., Univ. of Ill.
9967 Hollingsworth, C. R.
9968 Neal, D. E., Purdue Univ.
9969 Fee, H. McC., Purdue Univ.
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9979 Lewis, E. C., Univ. of Colo.
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9981 Murray, L. J., Univ. of Colo.
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9983 Baker, A. J., Case School of Applied Science
9984 Van Valkenburg, K. H., Cornell Univ.
9985 Macpherson, J. W., Cornell Univ.
9986 Spicer, H. McK., Cornell Univ.
9987 Clay, G. W., Jr., Cornell Univ.
9988 McCarthy, G. H., Cornell Univ.
9989 Hadaway, W. S., Cornell Univ.
9990 Benninghoff, W. E., Case School of Applied Science.
9991 Young, C. S., Case School of Applied Science.
9992 Gibson, R. D., Brooklyn, Poly. Tech. Inst.
9993 Wilson, G. E., Cooper Union
9994 Roblee, H. J., Case School of Applied Science.
9995 Cutts, R. C., Case School of Applied Science.
9996 Beardmore, A. E., Univ. of Minn.
9997 Ellsworth, C. DeR., Univ. of Minn.
9998 Kingsley, N. W., Univ. of Minn.
9999 Miller, J. S., Jr., Univ. of Va.
10000 Large, W. VanK., Colo. Agricultural Co.
10001 Peters, L. J., Univ. of Wis.
10002 Taylor, E. W., Penn. State Coll.
10003 McKenney, F. H., Univ. of Neb.
10004 Oswald, F. L., Univ. of Neb.
10005 Martin, J. S., Univ. of Neb.
10006 Yantz, V. U., Univ. of Neb.
10007 Reed, O. P., Univ. of Neb.
10008 Grayman, J., Brooklyn Poly. Inst.

Total 244

ADDRESSES WANTED

Any reader knowing the present address of any of the following members is requested to communicate with the Secretary at 33 West 39th Street.

Edward de A. Braga
(former address)
2-4 Stone St.,
New York, N. Y.

Howard K. Cook
(former address)
Counties Gas & Elec. Co.,
Norristown, Pa.

F. C. Dieterich
(former address)
17 Watertown Ave.,
Waterbury, Conn.

Nils Erricksson
(former address)
198 Baverly St.,
Toronto, Canada.

George Goldman
(former address)
6229 Rhodes Avenue,
Chicago, Ill.

A. Guerra
(former address)
Mexican Light & Power Company,
Mexico City, Mex.

H. S. Logan,
(former address)
214 15th Ave.,
Seattle, Wash.

Louis F. Nosek,
(former address)
2245 E. 82nd St.,
Cleveland, Ohio.

J. E. Penn,
(former address)
322 Champlain Ave.,
Cleveland, Ohio.

PERSONAL

Major William J. Hammer, who in civilian life is a consulting electrical engineer with offices at 55 Liberty St., New York City and who for some time past has served the War Department in the War Plans Division, was on December 13 appointed a member of the General Staff Corps.

Lewis S. Maxfield, until recently mechanical engineer for the Carver & Nate Company, Engineering Contractors, has accepted the position of Assistant to the Secretary of the Heating and Piping Contractors, National Association.

H. H. Clark, formerly Electrical Engineer of the U. S. Bureau of Mines, and during the war, Major in Chemical Warfare Service, has returned to civilian life as Chief Engineer of the Witherbee Igniter Company of Springfield, Mass.

F. L. Gilman resigned his position as Works Manager of the National Conduit and Cable Company last November and leaves for abroad in February, where he will take a position as European General Superintendent for the Western Electric Company, in charge of that Company's manufacturing plants in England and on the Continent.

E. H. Martindale who entered the service as Captain of Engineers Sept. 25, 1917 sailed for France February 1, 1918 and returned to the U. S. January 24, 1919. He was stationed in Angers, Tours, Paris and Nevers. At Angers he received additional training. At Tours he served in the electrical section of the Dept. of Construction and Forestry. At Paris he served with the Technical Board. At Nevers he was Engineer Officer in charge of construction of a 15,000-volt 35-mile transmission line for Mars and Mesves hospitals. He has returned to his former positions as Pres. and Gen. Mgr. of The Handy Supply Co., and as Sales Engineer of National Carbon Co. both of Cleveland, Ohio.

Leon W. Rosenthal formerly a consulting electrical engineer and patent solicitor of New York City, was elected a Vice-President of the American Bosch Magneto Corporation which, upon the sale by the Alien Property Custodian, acquired the interests of the Bosch Magneto Company. Mr. Rosenthal will make his headquarters at the factory in Springfield, Mass., but will also have an office in New York City at 223 West 46th St.

C. L. Clary has been made District Manager in charge of the St. Louis office of the Chuse Engine & Manufacturing Company. Mr. Clary has for the past five years been connected with the P-K Engineers of St. Louis.

ENGINEERING SERVICE BULLETIN

Opportunities.—The Institute, is particularly anxious to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in the BULLETIN. The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Services Available.—Under this heading brief announcements (not more than fifty words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office reference files.

Note.—Copy for publication in the BULLETIN should reach the Secretary's office not later than the 20th of the month if publication in the following issue is desired. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

OPPORTUNITIES FOR SERVICE

V-484. Public utility in the Middle West requires the services of a graduate electrical engineer who is interested in economic research relating to valuation, appraisal and profit sharing problems. State training, experience and salary desired.

V-485. Wanted—Electrical engineer who has had experience in designing alternating current generators and synchronous motors. Correspondence confidential. Answer to include age, experience, history of employment, salary expected.

V-486. Wanted—Technical man in the operation of ice making and refrigerating plants, of both absorption and compression systems, especially as regards to economical operation, also boiler and engine testing, efficiency determinations, etc. Must have practical experience along such lines. Reply by letter giving salary expected at start, and full details of experience and references. Location in the Middle West. The highest qualifications and broad knowledge of such work is essential. Good opportunity for young man of required experience and advancement assured in a permanent position. State how soon at liberty.

V-487. Technical graduate for position of assistant to general manager of 15,000 kw. central station in W. Va. Practical experience with power house switchboard and electrical apparatus, also operation. Must be able to analyze power house costs and carry on maintenance work of all equipment. Give experience, age and salary expected.

V-488. Stock room keeper. Man experienced in keeping stock of electrical motors and generators. Salary about $30. per week. Location Chicago.

V-489. Motor manufacturer, location New Jersey, wants one layout man and detailer, one detailer and tracer, and one designing draftsman familiar with A. C. and D. C. motors and generators.

V-490. Technical graduate, experienced in testing A. C. and D. C. motors. Man able to check tests. Salary $100. to $125. per month.

V-491. Wanted—A man to take charge of engine and boiler house of an industrial plant in Middle Western City as chief engineer. Applicant must be experienced, thoroughly capable of handling modern steam turbine generating station of 6000 kv-a. capacity and boiler plant of 5000 rated h.p. consisting of chain grate and Taylor stokers. Must have a thorough working knowledge of boiler and engine room practice, including the use of modern boiler efficiency instruments and methods and be a first-class mechanic capable of handling men. Replies should give complete education and experience of applicant, together with age, reference, salary expected, etc.

V-492. Technical graduate to eventually act as distribution engineer for power company. Location Nebraska. Three-phase, 4-wire, 2300-4000 volt system. Operating experience essential. Salary $130. up depending on experience.

V-493. Young man with sales ability. Must be experienced in the operation of motors and generators. State experience and salary expected to start. Excellent opportunity for advancement for the right man.

SERVICES AVAILABLE

1167. Manufacturing executive. Mechanical, electrical and some chemical manufacturing experience. Thoroughly familiar with organization necessary to secure quality and quantity production. Has been successful in reorganizing non-producing plants and securing production with reduced costs. Forty-six years of age, married. Now officer in U. S. service. Desires permanent connections.

1168. Engineering executive. Technical graduate. Experienced in isolated and central station power plants and central station heating plants. Chief executive three years of electric public utility and central station heating plant. Desires permanent connection where advancement is limited only by ability. Prefer East. Good personality, married, highest references. Salary $6000.

1169. Captain of Engineers, U. S· Army, graduate electrical engineer· seventeen years' experience including hydraulic, electrical and irrigation engineering and teaching, desires engineering or executive position with progressive electric utility, far west preferred.

1170. College graduate in electrical and mechanical engineering, University of Toronto, twenty-six years of age, married, Student Member of A. I. E. E. One year's experience on long distance telephone transmission. One year's experience on air compressors and hammer drills. One year's experience on steel treatment. Specialized in efficiency engineering during my last year in college. Available on two week's notice. Salary $150. per month.

1171. Wants position where experience as electric cable engineer will benefit. Twenty-eight years of age, married. Technical graduate in electrical engineering. Past eight years specialized in design, manufacture and testing of all types insulated conductors. Have made comprehensive study of theoretical and practical cable field. Experienced in estimating and planning improvements on manufacturing propositions. Minimum salary $1800. per year. Available two weeks' notice.

1172. Electrical and steam engineer, technical man with broad experience and knowledge of efficient methods of power production, desires position as manager of power company or railway company, or as power superintendent in an industrial plant. At present employed as advisory engineer. Prefer middle west location. Salary $5000.

1173. Engineer-Physicist. Graduate University of Chicago, Physics; graduate University of Wisconsin, electrical engineering; General Electric testing experience; six years teaching physics and electrical engineering; desires position in experimental or development work. Thirteen years laboratory training, high scholastic record, excellent health and very temperate habits. Age 32. Salary dependent upon opportunities.

1175. Assistant professor of mechanical and electrical engineering, with both practical and teaching experience, desires advancement to department head or other position of responsibility. Especially experienced in laboratory and lecture in gas engines and power plant practice, both mechanical and electrical.

1176. Graduate electrical engineer, three years' experience in maintenance and construction of substations for large power company, two years general engineering experience in the U. S. Navy in the application of Diesel engines; now commissioned in the Naval Reserve Force. Desires position with power company or manufacturing company. Available about the first of May.

1177. Lieutenant U. S. Army, graduate electrical engineer, desires position with electrical power or construction company in the East. Experience: one year graduate work and laboratory assistant, Yale University; three months high tension power transmission line design and construction; one and one-half years central station construction; fifteen months electrical work U. S. Army. Available April 1st. Salary $175. per month.

1178. Electrical engineer, college graduate, age 26, single, experienced in substation design, two years Westinghouse test and as assistant to the plant superintendent of a large steam generating plant, desires position requiring executive and technical ability. Canada or Eastern States preferred. Services available on month's notice. Salary $175. per month.

1179. 1913 technical graduate in electrical engineering wants a $200. job. Six years varied central station experience; sub-station construction, overhead and underground distribution, consulting engineer's office, power plant design. Twenty-eight years old, married. Available on two weeks' notice to present employer.

1180. Head of department of electricity and telephony at a well-known correspondence school desires position as assistant professor of electrical engineering, physics or mechanical engineering. Technical graduate 1910, degree M.E., four and one-half years practical experience in electrical and mechanical engineering. In present position nearly five years. Age 34. Married. Available on one month's notice.

1181. Young electrical engineering graduate with two years general engineering experience and one year specialized switchboard design experience desires to locate with live, moderate sized central station. Combination of commercial and engineering work preferred. At present in Signal Corps, with prospect of early discharge. Best of references.

1182. Engineer and executive. Technical graduate with nine years varied experience along electrical engineering and administrative lines. Want position as power salesman, efficiency engineer, or manager of power company in town of about 20,000. Age 31, married. Available on short notice.

1183. College graduate, keen, broad minded, desires to work for live firm (or individual). Has electrical and mechanical training. Not afraid of work and will consider any line in which capable work will bring advancement.

1184. Electrical and mechanical engineer, technical graduate, age 28, now engaged in development and design work in engineering department of large electrical manufacturing concern, wishes to take up similar work with opportunities for advancement. $1800.—$2200.

1185. Engineer of broad experience desires position, executive. Would be valuable to financial interests, holding company or consulting engineer to make thorough commercially practical examination and report on public utility properties. (rates, condition of physical property, earnings, etc.) or other technical enterprise. Could adapt self to your particular requirements for a general superintendent or chief engineer and deliver the goods. Initial salary $4500.

1186. Technical graduate 1910, age 30. Six years street lighting and distribution; six years meter and instrument testing and design, heating and miscellaneous apparatus. Desires position with growing concern. Salary $2400. Location near New York City.

1187. Electrical engineer, graduate, Associate A. I. E. E., age 32, single, six years' experience general electrical engineering, installation, maintenance and repairs of electrical power house equipment, high tension apparatus, meters, and power distribution. Considerable experience with internal combustion engines. Desire position with good engineering company or will accept temporary position as assistant superintendent in large capacity turbo-steam plant.

1188. Professor of electrical engineering in an eastern university desires to make a change at the end of the college year. Author of a text-book. Practical experience. Age 40. Will be in New York City for interview the latter part of March.

1189. Position wanted by mechanical and civil engineer. Experience four years on railroad, highway and building construction; one year as machinist apprentice; one year in banking buisness; two years obtaining practical experience in power station operation; one year efficiency engineer on power station work; one year as M.E. on appraisal of power plants; six months as M.E. in charge of shop erection and design for a super-heating concern. Just returned from fourteen months service overseas as Captain Engineers. Graduate C.E. and M.E. Married, age 35. Available April 1.

1190. Electrical engineer age 28, married, desires position as road salesman with electrical supply house. Fifteen years practical experience, also some road experience.

1191. Graduate electrical engineer with ten years practical and executive experience in research and development with large electrical manufacturer, desires position as assistant to manager or assistant to chief engineer of company manufacturing electrical apparatus.

1192. Position offering problems and investigations desired, where the following experience would be of service: electrical manufacturing company, assembly and tests, three years; operating company, switchboard design, five years; State University, electrical engineering laboratory instruction, four years: with consulting engineer, present employer, three years. Available April 1. Salary $2400.

1193. Electrical designer in charge of men on large power stations. Experience: college, two years shop practice and twelve years electrical and mechanical design. Twice chief draftsman. Last three years with present consulting engineers. Available on month's notice.

Best references. Prefer position as construction engineer. Age 35. Married. Associate A. I. E. E.

1194. Graduate electrical engineer, two years' experience in erecting and operating electric furnaces, desires a position as melter and electrical engineer. Salary $2400. a year.

1195. Graduate electrical engineer 1907, age 36 years, at present with consulting engineering company. Desires to make a change. Seven years in charge of power house and substation construction for light and power company. Also considerable maintenance experience. Can give references and additional information. Salary expected $3600.

1196. Captain of Engineers, served one year in France, Member A. I. E. E., President and General Manager of a small supply company doing a good business on a limited line is looking for agencies for electrical supplies to be sold to present trade throughout the country or for exclusive agencies for Cleveland or Northern Ohio. Let a good live organization help keep your factory busy.

1197. Ensign, U. S. Naval Aviation. Executive, electrical engineer, just returned service abroad. Ignition and storage battery specialist. Education; Massachusetts Institute of Technology and in plants abroad. Desire position as sales engineer for big manufacturer where there is opportunity to expand. Minimum salary $5200. per annum.

1198. Electrical engineer. Married, age 26, just returned from foreign service. Desires position with public utility company. Graduate University of Illinois, 1915, graduate Chicago Central Station Institute, 1916, having spent half-time for eleven months in the operating, voltage regulation, estimating, power sales, lighting sales and other departments of the Commonwealth Edison Company. Ten months' experience in the Contract Department of the Commonwealth Edison Company.

1199. Engineer executive, who can organize and direct industrial power work, consulting or managing capacity. Graduate electrical engineer, G.E. test, unusually broad experience industrial motor application, selection, layout, purchase and maintenance power equipment, with particular reference to factory production. Expert on heavy currents. Captain in charge important Government production division. Available immediately. Age thirty-two.

1200. Technical graduate electrical engineer, Associate A. I. E. E., desires position where executive ability and tact is required. Eight years experience as consulting engineer and contractor in illuminating engineering, power distribution and control, both interior and exterior installation. Until recently with War Department, Washington, D. C., as consulting engineer on illumination.

1201. Position as industrial manager or shop superintendent sought by Lieutenant, U. S. N. R. F., to technical graduate, age 32. Ten years' experience in the design, manufacture, installation and operation of electrical machinery; generating, a. c. and d. c., sub-station operation, high and low tension distribution. Minimum salary $4000.

1202. Advertising man, technical graduate, three years' experience in publicity department of large electrical manufacturing company, seeks position as advertising manager, or assistant manager, with manufacturer of technical product, or merchandising and publicity manager of central station. Awaiting early discharge from U. S. Army.

ACCESSIONS TO THE ENGINEERING SOCIETIES LIBRARY

(From January 1st to January 31, 1919)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

AMERICAN HIGHWAY ENGINEERS, HANDBOOK:

Editor-in-chief, Arthur H. Blanchard, 1st ed. N. Y., John Wiley and Sons, Inc.; Lond., Chapman and Hall, Ltd., 1919. 1658 pp., illus., tab., 7 x 4 in., flexible cloth, $5.

The task undertaken has been the compilation of a reference book which would include reliable and comprehensive information on all branches of highway engineering and related subjects, including organization and administration of highway departments, financing of improvements, highway design, paving, testing, costs, etc. These questions are discussed in twenty-nine sections, each of which has been edited by an authority. Bibliographies for each section and an extensive index have been provided.

AMERICAN METHODS IN FOREIGN TRADE:

A Guide to Export Selling Policy. By George C. Vedder. 1st ed., N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1919. 204 pp., 8 x 6 in., cloth, $2.00.

The author of this volume is a believer in the soundness of the distinctively American methods of developing an export trade which have hitherto been adopted by our most efficient world traders. He attempts in the volume before us to explain how these firms have achieved success and to outline the proper policy to be adopted by those interested in entering foreign markets.

CHILTON TRACTOR INDEX:

Published semi-annually by the Chilton Co., Phila., Jan., 1919. 464 pp., 10 x 7 in., paper. $1.00.

The Tractor Index is a directory of the manufacturers of tractors, tractor parts and accessories, and power farming machinery in the United States. It also includes an illustrated list of American tractors, in which brief specifications for each tractor are given, a table giving complete specifications for one hundred ninety-eight tractors, and a similar table of specifications for power farm machinery. A collection of articles on tractors and farm machinery complete the work.

CHLORINATION OF WATER:

By Joseph Race. 1st ed. N. Y., John Wiley and Sons, Inc., 1918. 158 pp., 8 x 5 in., cloth, $1.50.

CONTENTS: Historical, Modus Operandi, Dosage, Bacteria Surviving Chlorination, Complaints, Bleach Treatment, Liquid Chlorine, Electrolytic Chlorine and Hypochlorites, Chloramine, Results Obtained, Appendix.

The author has collected and correlated the scattered information in print on the purification of water by chlorine, and presents a systematic account of the theory, practical application and results. Numerous references to the original publications are given.

CLASSROOM LECTURE NOTES:

Automotive Starting, Lighting and Ignition. By R. C. Fryer. 2d ed., N. Y., John Wiley and Sons, Inc.; Lond. Chapman and Hall, Ltd., 1918. 210 pp., diag. 8 x 5 in., cloth, $1.25.

The author provides a general, concise, series of notes, including the essential knowledge needed by the student, but requiring enlargement by the instructor. Eighty-eight pages of wiring diagrams are given.

THE FUNDAMENTAL EQUATION OF DYNAMICS:

And Its Main Coordinate Systems Vectorially Treated And Illustrated From Rigid Dynamics. By Frederick Slate—Berkeley University of California Press, 1918. 233 pp., 8 x 6 in., cloth, $2.

The author of this volume feels that the extensiveness of the field of dynamics has necessitated such compression in the general surveys of its principles that the usual treatment leans too heavily on mathematics. His desire has been to prepare a supplement to such standard works which will direct attention to the physical aspects, and to experimental reasoning, by offering a flexible continuation of an elementary stage with unsettled achievement. The book forms part two of "Principles of Mechanics" (Part one, Macmillan Co., 1900).

A HANDBOOK OF PHYSICS MEASUREMENTS:

Vol. I. Fundamental Measurements, Properties of Matter, and Optics. Vol. II., Vibratory Motion, Sound, Heat, Electricity and Magnetism. By Ervin S. Ferry, in collaboration with O. W. Silvey, G. W. Sherman, Jr., and D. C. Duncan. 1st ed., N. Y., John Wiley and Sons, Inc.; Lond., Chapman and Hall, Ltd., 1918, 251 + 233 pp., illus., tab., 8 x 5 in., cloth, $2 a volume.

The aim of this work is to furnish the student of pure or applied science with a self-contained manual of the theory and manipulation of those measurements in physics which bear most directly upon his subsequent work in other departments of study and upon his future professional career. The experiments have been selected with regard to the particular determinations now demanded by science and industry and so grouped as to segregate those of value for students of the various branches of engineering.

MAKING THE SMALL SHOP PROFITABLE:

By John H. Van Deventer. 1st ed. N. Y., published by The American Machinist. (McGraw-Hill Book Co., sole selling agents), 1918. 113 pp., illus., 12 x 9 in., 1/4 cloth, $1.75.

This book contains a series of articles on important phases of the activities of small machine shops, proper methods of working, cost-keeping etc., and also illustrations of many handy devices for facilitating work, particularly in shops with limited equipment. It is a continuation of the author's "Success in the Small Shop". The articles first appeared in the American Machinist.

PRACTICAL OIL GEOLOGY:

The Application of Geology to Oil Field Problems. By Dorsey Hager. 3rd ed., N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Pub. Co., Ltd., 1919. 253 pp., 126 illus., 37 tab., 7 x 5 in., flexible cloth. $2.50.

The author of this handbook has aimed to provide a clear, concise and practical work on the occurrence of oil and its geology, based on American practise. The present edition, the third in four years, has been thoroughly revised, enlarged and reset.

THE SILK DIRECTORY:

Davison's Silk Trade. Office edition. A Directory of the Silk Manufacturers of the United States and Canada including Silk Dyers, Finishers and Printers; Manufacturers' Agents; City Offices and Salesrooms of Silk Mills; Dealers in Raw, Thrown, Spun and Artificial Silk; Waste; Cotton, Tinsel and Worsted Yarns; Silk Jobbers and Retailers and a Classified Directory of All Manufacturers of Silk Goods. 23rd annual edition. 1918. N. Y., Davison Publishing Co., (copyright 1918), 778 pp., 8 x 6 in., cloth, $3.50.

The directory includes dyers, finishers, printers, manufacturers' agents, city offices and salesrooms of mills, dealers, jobbers, retailers and manufacturers. These are given in lists classified primarily by occupation and secondarily by location. The lists have been carefully revised and enlarged by the addition of new establishments.

STEAM ENGINES:

Prepared in the Extension Division of the University of Wisconsin by E. M. Shealy. (Engineering Education Series.) 1st ed., N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1919. 290 pp., 173 illus., 9 x 6 in., cloth $2.50.

This is the third of a series of three text books of steam engineering, prepared for correspondence students in the University of Wisconsin Estension Division. The aim in this volume is to teach the fundamental principles underlying the operation of the steam engine, in as simple and non-mathematical a manner as possible. Particular attention is given to valve gears.

THE THEORY OF ELECTRICITY:

By G. H. Livens. Cambridge, Eng. The University Press, 1918. 717 pp., 11 x 7 in., cloth, $8.25. (Gift of G. P. Putnam's Sons.)

Dissatisfaction with the treatment of this subject in standard textbooks, which the author believes to be incomplete, often inconvincing and sometimes erroneous, leads him to offer this work as a general textbook on the mathematical aspects of modern electrical theory in which an attempt is made to present the complete subject in a consistent form.

Although his exposition is essentially a mathematical one, much of the purely analytical mathematics usually associated with the subject has been omitted. Particular attention has, however, been given to the rigorous formulation of underlying physical principles and to their translation into a mathematical theory. The dynamical aspects of the subject have been specially emphasized throughout.

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Board of Trustees, United Engineering Society
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Joint Committee on Engineering Education
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Advisory Board of American Year-Book
U. S. National Committee of the International Illumination Commission
National Joint Committee on Overhead and Underground Line Construction
American Committee on Electrolysis
Engineering Council
Electrical Engineering Section of Engineering Division, National Research Council
Engineering Foundation Board
Naval Consulting Board
American Engineering Standards
Commission of Washington Award
Pan-American Engineering Committee

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*A complete list of the officers, committees and representatives of the Institute will be found in the January, 1919, issue of the Proceedings.

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Washington, Univ. of, J. R. Tolmie, Walter H. Weber
West Virginia Univ.
*Worcester Poly. Inst.
Yale University, P. C. O'Brien, Donald F. Hine

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*Inactive at present, due to the war.

PROCEEDINGS

OF THE

American Institute of Electrical Engineers

Vol. XXXVIII
Number 4

APRIL, 1919

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TABLE OF CONTENTS

Section I.—Institute Affairs

Joint A. I. E. E. and I. E. S. Meeting in New York, April 11, 1919 127
Future A. I. E. E. Meetings 127
Report of Committee of Tellers on Nomination Ballots 128
Meeting of Radio Engineers 128
The Boston Meeting 129
Exhibit of Army Personnel Work 130
The J. E. Aldred Lectures on Engineering Practise 130
United Engineering Society. Extracts form Treasurer's Annual Report for Year Ending Dec. 31, 1918 131
Engineering Foundation. Abstract of Annual Report for Year Ending Feb. 20, 1919 132
Engineering Council. Extracts from Annual Report for Year Ending Feb. 20, 1919 134
United Engineering Societies Library Report 138
Past Sections Meetings 140
Past Branch Meetings 142
Associates Elected March 14, 1919 143
Associates Re-elected March 14, 1919 148
Members Elected March 14, 1919 148
Transferred to Grade of Fellow March 14, 1919 149
Transferred to Grade of Member March 14, 1919 149
Transferred to Grade of Member February 19, 1919. Correction 149
Recommended for Transfer 149
Applications for Election 149
Students Enrolled March 14, 1919 152
Personal 153
Obituary 154
Engineering Service Bulletin 154
Accessions to Engineering Societies Library 158

Section II.—Papers and Reports

Electromagnetic Theory of the Telephone Receiver. By A. E. Kennelly and H. Nukiyama, Boston, Mass., March 14, 1919 491
Some Possibilities of Steam Railroad Electrification as Affecting Future Policies. By Calvert Townley, Boston, Mass., March 14, 1919 541
Engineering and Industrial Standardization. By C. A. Adams, New York, February 20, 1919 549
Welding Mild Steel. By H. M. Hobart, New York, February 20, 1919 561
Present Status of Industrial Lighting Codes. By G. H. Stickney, New York, April 11, 1919 611

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American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXVIII APRIL, 1919 Number 4

JOINT A. I. E. E. AND I. E. S. MEETING IN NEW YORK APRIL 11, 1919

The 349th meeting of the American Institute of Electrical Engineers will be held in New York, April 11th, 1919, at 8:15 p. m. in the Auditorium of the Engineering Societies' Building, 33 West 39th Street, New York.

The meeting will be held under the auspices of the Lighting and Illumination Committee and will be a joint meeting with the Illuminating Engineering Society.

A paper will be presented entitled *Present Status of Industrial Lighting Codes* which has been prepared by Mr. G. H. Stickney on behalf of both the Illuminating Engineering Society, and the Lighting and Illumination Committee of the Institute, which will give an outline of the necessity and scope of such codes together with an analysis of the specifications of such items as the intensity, limits of glare and distribution of illumination as related to modern industrial lighting.

The paper will include references to the adoption of lighting codes by the Departments of Labor in such states as Pennsylvania, New Jersey, New York and Wisconsin with a reference to the cooperative work which has been done between the Committee on Labor, Council of National Defense, and the Illuminating Engineering Society in placing adequate industrial lighting regulations before the state authorities generally throughout the country.

A large number of engineers engaged in the applications of electric lamps and auxiliaries to the industries, works managers, and also prominent members of state labor departments have been invited to contribute to the discussion.

FUTURE A. I. E. E. MEETINGS

May Meeting: The 350th meeting of the Institute will be the Annual Business Meeting held at Institute headquarters, New York, May 16, 1919. At this meeting the annual report of the Board of Directors will be presented and announcement made of the election of officers for the ensuing year. The feature of chief interest at this meeting will be the ceremonies in connection with the presentation of the Edison Medal.

Annual Convention: As previously announced, the Annual Convention of the Institute this year will take place at the Lake Placid Club, Adirondacks, New York, on June 24 to 27, inclusive. As it is expected that a considerable amount of time will be devoted this year to the consideration and discussion of Institute affairs and policies as outlined in the communications from the Committee on Development in the March PROCEEDINGS, the usual number of technical sessions has been curtailed with a view to leaving ample time for carrying out the program of the Committee on Development as well as for social and entertainment features which the Lake Placid Club affords. The detailed program is under consideration by the Meetings and Papers Committee and the Convention Committee and will be published in the May issue. The members of the Convention Committee are—Messrs. Farley Osgood, Chairman N. A. Carle; Walter A. Hall, Edward Kilburn, W. L. Merrill, George F. Sever, W. I. Slichter and C. W. Stone.

REPORT OF COMMITTEE OF TELLERS ON NOMINATION BALLOTS

March 6, 1919

To the Board of Directors, American Institute of Electrical Engineers.

Gentlemen: This Committee has counted and canvassed, in accordance with Article VI of the Constitution, the nomination ballots received for officers of the Institute for 1919-1920. The result is as follows:

Total number of envelopes said to contain ballots, received from the Secretary		1249
Rejected on account of bearing no identifying name on outer envelope	70	
Rejected on account of having reached Secretary's office after Feb. 28	34	
Envelopes received containing no ballots	26	130
Leaving as valid ballots		1119

These valid ballots were counted and the result is shown below:

FOR PRESIDENT

Calvert Townley	1008
*J. Franklin Stevens	46
Scattering and blank	65
Total	1119

*Candidate had requested, prior to balloting, that his name be withdrawn.

(The scattering vote was divided among 11 candidates, each of whom received less than 3% of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices.)

FOR VICE-PRESIDENTS

C. E. Skinner	978
John B. Fisken	964
N. A. Carle	952
J. B. Whitehead	869
L. R. Jorgensen	827
Wills Maclachlan	817
A. M. Schoen	770
Scattering and blank	537
Total	6714

(The scattering vote was divided among 59 candidates, each of whom received less than 3% of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices.)

FOR MANAGERS

L. E. Imlay	1034
L. F. Morehouse	1031
F. F. Fowle	1018
Scattering and blank	274
Total	3357

(The scattering vote was divided among 36 candidates, each of whom received less than 3% of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices.)

FOR TREASURER

George A. Hamilton	1015
Scattering and blank	104
Total	1119

Respectfully submitted,
HENRY C. CLEMENT, *chairman*
CHAS. M. LEE,
I. W. EDWARDS,
P. C. PAQUETTE,
JAMES GOLDSBOROUGH.
Committee of Tellers.

MEETING OF RADIO ENGINEERS

The next meeting of The Institute of Radio Engineers will be held on Wednesday evening, April 2nd, 8:15 p. m., in Room 2, on the Fifth Floor of the Engineering Societies Building, 33 West 39th Street, New York City.

A paper will presented by Mr. E. F. W. Alexanderson of the General Electric Company on "Simultaneous Sending and Receiving." Some highly interesting results relative to duplex radio telegraph and radio telephone operation are given, together with highly selective and stray reducing receivers.

Members of the A. I. E. E. are cordially invited to attend, and those who desire to receive notices of future meetings may have their names placed upon the mailing list of the Institute of Radio Engineers upon request to the Secretary, Prof. A. N. Goldsmith, College of the City of New York, New York.

THE BOSTON MEETING

The 348th meeting of the Institute was held at the Copley-Plaza Hotel, Boston, Mass., March 14, 1919. This meeting was somewhat of an innovation as it provided for morning, afternoon and evening sessions and presented a number of papers and addresses on widely divergent subjects. The meeting proved to be an unusually successful one and the attendance was so large as to tax the capacity of the meeting rooms at all the sessions.

The morning session was called to order promptly at 10 o'clock by President Comfort A. Adams who introduced Governor Calvin Coolidge of Massachusetts. After brief addresses of welcome by Governor Coolidge and President Adams, Mr. Calvert Townley presented his paper on "Some Possibilities of Steam Railroad Electrification as Affecting Future Policies." Mr. Townley's paper, which is published in this issue of the PROCEEDINGS, drew forth an interesting discussion covering the future possibilities of electrification of steam railroads and the closely related subject of coal and oil fuel conservation. Among those taking part in the discussion were F. H. Shepard, W. S. Murray, Carl Schwartz, N. W. Storer W. B. Potter, George F. Sever, A. G. Webster, Charles F. Scott, John Murphy and George Gibbs.

At 12:30, after the close of the morning session, the Board of Directors and a number of other guests were entertained at luncheon by the Executive Committee of the Boston Section.

The afternoon session was devoted to the subject of Telephony and was called to order by President Adams at 2:00 p. m. After calling the meeting to order President Adams turned it over to Mr. Ira M. Cushing, Chairman of the Boston Section, who presided during this session. The first paper of the afternoon was entitled "Electromagnetic Theory of the Telephone Receiver with Special Reference to Motional Impedance" by A. E. Kennelly and H. Nukiyama. The paper was abstracted by Dr. Kennelly. The next paper was by Prof. A. G. Webster on "The Absolute Measurement of the Intensity of Sound." Prof. Webster described in detail several instruments which he had devised, and illustrated his remarks with numerous lantern slides and also exhibited his instruments. The discussion which followed was by John B. Taylor, T. E. Shea, B. A. Behrend, R. L. Jones and Harold S. Osborne.

At 2:30 p. m. the Board of Directors held its regular monthly meeting, and at 6:00 p. m. a subscription dinner which was largely attended was served. After dinner a number of very interesting addresses were made on the general subject of engineering education, the speakers being Prof. Harry C. Clifford, Prof. E. B. Wilson, Dr. Charles W. Eliot, Dr. A. G. Webster, and Dr. Saul Dushman.

At the Board of Directors meeting held in the afternoon of March 14, the following resolution was adopted:

> RESOLVED, that the Board of Directors of the American Institute of Electrical Engineers hereby expresses its hearty appreciation of the services rendered by the officers and committees of the Boston Section in making and carrying out with gratifying success, the plans for the Institute meeting held in Boston, March 14, 1919.

The members of the Executive Committee of the Boston Section are—Messrs. Ira M. Cushing, Chairman, W. H. Timbie, Vice-Chairman, Harry M. Hope, Retiring Chairman, H. M. Myers, Assistant Secretary, B. A. Behrend, R. A. Langworthy, R. R. Lawrence, Edward T. Foote, and C L. Kasson. The members of the Committee on Arrangements are—Messrs. B. A. Behrend, Chairman, Dr. A. E.

Kennelly, Prof. W. S. Franklin, and the members of the Executive Committee.

EXHIBIT OF ARMY PERSONNEL WORK

Members of the Institute and others interested in personnel work will have an opportunity to examine the methods developed by the Committee on Classification of Personnel in the Army at an exhibit to be shown on the auditorium (third) floor of the Engineering Societies Building 33 West 39th Street, New York City, April 1st to 12th, 1919. The exhibit consists of a collection of wall charts, forms, photographs and models showing how the Army finds out what men can do best and how it uses that information; how soldiers are trade tested, and how officers are rated and fitted into place; how the work is checked and supervised, and its results in the war.

The collection is being shown under the auspices of the National Association of Corporation Schools and several national engineering societies, including the Institute. It was on exhibition for several weeks at Washington, where it excited so much interest that in response to many requests the Adjutant General consented to its display in other cities. Two commissioned officers accompany the exhibit to explain its various features.

THE J. E. ALDRED LECTURES ON ENGINEERING PRACTISE

Through the generosity of Mr. J. E. Aldred there has been founded in the Department of Engineering, Johns Hopkins University, Baltimore, Md., a course of lectures on Engineering Practise. The course of lectures is one feature of a general plan for furthering and improving undergraduate instruction in the methods and problems of the practise of engineering.

The lectures will deal, therefore, with the practical phases of engineering problems, rather than with theory. They are not expected to discuss new and striking applications, as much as to deal with every-day working methods of design, construction and operation.

Since the lectures are planned especially for undergraduate students, they will presuppose an elementary rather than an extensive knowledge of underlying theory, and will lay special stress on the tangible and obvious features and principles of practical engineering of the present day.

During the year 1918-1919 three lectures each will be given in the general subjects, Civil, Electrical, and Mechanical Engineering. They will be given on Wednesday afternoons at 4.45 o'clock, on the dates shown on the accompanying list, in the auditorium of the Mechanical and Electrical Engineering Building of the University, at Homewood.

The requisite number of seats in the lecture hall will be reserved for the student body. There will, however, be ample additional space, and engineers or others who may be interested will be welcomed. The lectures are open to the general public, and tickets of admission are not required.

April 2nd "The Modern Steel Freight Ship". Mr. D. D. Thomas, Chief Engineer, Baltimore Dry Docks & Shipbuilding Company, Baltimore, Md.

April 9th "The Duties of the Young Engineer on the Construction of a Hydro-Electric Plant." Mr. H. S. Slocum, Consulting Engineer, of New York City.

April 30th "The Production of 50% Ferro-Silicon in the Electric Furnace." Mr. P. H. Falter, Shawinigan Electro Products Company, Baltimore, Md.

May 7th "Ore Docks on the Great Lakes". Mr. John E. Greiner, Consulting Engineer, of Baltimore, Md.

May 14th "Disturbing Currents in Telephone Systems." Mr. John B. Taylor, Consulting Engineer, General Electric Company, Schenectady, N. Y.

UNITED ENGINEERING SOCIETY

Extracts from Treasurer's Annual Report for Year Ending December 31, 1918

The Surplus Account on December 31, 1917, showed a balance of $8,116.10. This amount has been increased by the surplus from the operating accounts during the year of $5,417.33, making a total on December 31, 1918, of $13,533.43. Of this amount $8,000.00 has been transferred to Depreciation and Renewal Fund, leaving a balance in Surplus Account of $5,533.43.

The *Gross Operating* Expenses for the year 1918 were $66,505.57.

The *General Operating* Expenses during the year 1917 were $53,791.97, showing an increase for the year 1918 of $12,713.60, partly due to the three additional stories first occupied in October 1917.

The funds available for the Library Board, and spent under their direction during the year, amounted to $28,740.29

The *General Reserve Fund* of $10,000 created by the Board of Trustees at a meeting held November 18, 1914, to be available to take care of unforeseen fluctuations of income and outlay, has been preserved intact there arising no calls on this fund during the year 1918.

The *Depreciation and Renewal Fund* at the beginning of the year 1918 amounted to $75,037.41. During the year this fund has been increased by the sum of $3,126.37 for interest earned by the investments for this fund during the year and accruals, and by $8,000.00 added from the surplus at the end of the year, making a total of $86,163.78 on December 31, 1918.

In accordance with the authorization of the Board of Trustees September 26, 1918, the sum of $10,000 was invested in 4th Liberty Loan Gold Bonds 4¼%.

The following summary shows the amounts of the funds held by U. E. S. as of December 31, 1918.

Depreciation and Renewal Fund Dec. 31, 1917....	$75,037.41
Interest on invested funds during the year 1918...	3,126.37
Transfer for the year 1918	8,000.00
Total..............	$86,163.78
General Reserve Fund...	10,000.00
Engineering Foundation Fund................	303,374.80
Library Endowment Fund	102,559.70

ASSETS AND LIABILITIES

December 31, 1918

Assets

Real Estate	$1,947,171.16
Investments Engineering Foundation Fund	303,321.25
Investments Library Endowment Fund	102,297.50
Investments General Fund...............	85,725.00
Cash	12,869.60
Petty Cash............	100.00
Unexpired Insurance ...	5,958.76
Accrued Interest Receivable	2,392.02
Accounts Receivable General.............	542.58
Bills Receivable........	12,500.00
	$2,472,877.87

Liabilities

Founders Equity in Property................	1,947,171.16
Due the General Reserve Fund...............	10,000.00
Due the Depreciation and Renewal Fund...	86,163.78
Due the Library Endowment Fund..........	102,559.70
Due the Engineering Foundation Fund	303,374.80
Due for notes payable A. S. M. E.	12,500.00
Due for Accounts Payable	2,090.24
Due for Library 1918 unexpended Balance....	274.26
Due for Library Service Bureau 1918 Surplus.	800.29

Due for Engineering Council 1918 Unexpended Balance......	2,410.21
Surplus (Dec. 31, 1918).	5,533.43
	$2,472,877.87

ENGINEERING FOUNDATION

Abstract of Annual Report for Year Ending February 13, 1919

Most conspicuous among the year's events are Ambrose Swasey's additional gift of $100,000 for the Endowment Fund and the increase in the membership of the Board from eleven to sixteen by amending United Engineering Society's By-Laws April 25, 1918. By the same amendment an Executive Committee of five was provided for. The endowment now amounts to $303,374.80. Income from the addition runs from September 1, 1918. Total income for the calendar year 1918 was $10,929.67. Expenditures were:

Salaries	$5,588.00
Office Expenses	580.46
Traveling Expenses	177.33
Stationery and Printing	184.05
Furniture	74.68
Gear Tests	633.97
Investigation of Wireless Control	237.27
Petty Cash	15.00
Total	$7,490.76

The accumulated unexpended income balance January 1, 1919 was $30,253.88.

Appropriations have been authorized for the following items, on which expenditures may be made during the calendar year 1919:

Budget for Ordinary Expenditures...	$8,200.00
Gear Tests, unexpended balance.....	207.73
Investigation of Wireless Control, unexpended balance	262.73
Tests of Weirs for Measurement of Water	2,500.00
Research in Mental Abnormalities...	600.00
Total	$11,770.46

Anticipated income for 1919 is approximately $15,000. Adding this to the January 1 balance and deducting the total obligations already incurred, there remain available for appropriation during this year, in round numbers, $33,000.

During the year, the Board had four regular meetings, one special meeting May 28, to act upon cooperation with the National Research Council in promotion of industrial research, and one joint meeting with United Engineering Society, October 7, to receive Mr. Swasey's second gift. November 14, United Engineering Society gave a dinner to Mr. Swasey.

The Executive Committee was completed September 12, by the election of Charles Warren Hunt and Silas H. Woodard, who with the Chairman and the two Vice-Chairmen constitute that committee.

Cooperation with the National Research Council has been continued. Through the "Industrial Research Section" and in other ways Engineering Foundation has taken part in the preliminary steps toward the organization of a Refractories Research Corporation and an American Zinc Association. Engineering Foundation also collaborated with National Research Council in gathering information regarding Mexico and Russia for the Military Intelligence Division of the U. S. Army.

An important new industry which has been growing rapidly in recent years is that of welding. Engineering Foundation has been taking part, through Dr. Jacobus and its Secretary as special delegates, in the work of committees on the organization of the American Welding Society for the direction and support of research and the development of this art.

In May, an investigation of spray camouflage for ships was completed with the conclusion that it was not practical. Professors G. H. Marx and L. E. Cutter have continued under the auspices of the Foundation, their investigation of the wears of gears. In March an investigation of the secret selective control of wireless communication was undertaken under the direction of Dr. Pupin.

In December, an investigation of weirs for measurement of water was authorized to be conducted under the personal direction of Clemens Herschel. At the same time a preliminary investigation of mental abnormalities, especially among employees in engineering industries, was authorized to be conducted under the supervision of Dr. E. E. Southard, of the Massachusetts Commission on Mental Diseases. A committee of three appointed by the Executive Committee December 31, is making a preliminary inquiry into the advisability of promoting the establishment of a testing station for large water wheels and other large hydraulic equipment.

As an aid to promotion of industrial research, there was assigned to the Secretary the task of collecting information about laboratories connected with the industries, which devote some time to research. At the June, 1918 meetings of American Society for Testing Materials, the Secretary contributed a paper entitled, "Development of Existing Agencies" in which was given a list of 350 laboratories said to devote at least part-time to research. This inquiry has been pursued to the present time. Letters have been sent to 1603 laboratories. The useful data collected are being classified. To aid in this work, a simple classification was prepared with the assistance of members of Engineering Foundation and National Research Council.

May 2, in the Engineers' Club, New York, a dinner was given to Dr. George E. Hale, Chairman, National Research Council, by the Presidents and Secretaries of the four Founder Societies, at which were present also five representatives of that Council and representatives of Engineering Foundation. The relations of the National Research Council to the engineering societies were discussed. A large public meeting in the Auditorium of Engineering Societies Building was held May 28, under the auspices of Engineering Foundation, at which Dr. Hale delivered a most instructive address upon the origin and work of the National Research Council.

January 23, the Chairman and officers of the National Research Council gave a dinner at the University Club, New York, to some of the officers of the National engineering and other societies, at which relations of engineers and especially Engineering Foundation, with National Research Council, were again discussed. It was voted to be the sense of the meeting that "the present representatives of the National engineering societies and National Research Council should continue to serve as representing the National engineering societies and form the nucleus of the Engineering Division in the new organization of the Research Council."

In order to reduce to definite terms some of the suggestions made January 23, an informal committee meeting was called January 24 by the Chairman of the Foundation. It was the sense of this meeting that:

1. Engineering Foundation and the Engineering Division of National Research Council should be closely allied, but each should retain its identity;

2. Engineering Foundation should contribute definitely to the support of the Engineering Division, but should not become merely a disbursing agency for the Division;

3. Private financial support for the Engineering Division was much to be preferred to governmental appropriations;

4. The Engineering Division should be composed of;

(a) Three representatives apiece from the Civil, Mining, Mechanical and Electrical engineering societies and one each, from other national engineering societies admitted to membership in Engineering Council;

(b) About four members at large (one-fifth to one-quarter of the total membership of the Division) suggested by the Executive Board of the National Research Council;

(c) Three liaison members from other divisions having interlocking interests (physics and chemistry) with right to vote, except for chairman of Engineering Division;

5. The Engineering Division should have an executive committee of five members chosen by the Division;

6. The Engineering Division should organize itself into sections and committees, to include members outside the Division.

The year has been one of modest activity and of constant search for the right fields for larger service. War's unsettling effects and enforced changes in the development of National Research Council have had an unescapable influence upon the Foundation's plans. Engineering Foundation is stronger than ever before, and ready for the large work just ahead.

ENGINEERING COUNCIL

Extracts from Annual Report for Year Ending February 20, 1919

Engineering Council has completed its second year. Notable in the year's history are: service to the Government in connection with the German war; creation of Engineering Societies Employment Bureau, establishment of a Washington office, appointment of a committee on Licensing of Engineers, and the admission of an additional member society. Through visits made by the Secretary mutually helpful relationships with engineering societies in twenty-five or more localities were established.

Engineering Council held six regular meetings beginning with the Annual meeting February 21, 1918, and one special meeting on November 21, all in Engineering Societies Building, New York. There was no change in the officers as elected at the beginning of the year: J. Parke Channing, Chairman, Harold W. Buck, 1st Vice-Chairman, George F. Swain, 2nd Vice-Chairman, Alfred D. Flinn, Secretary. For the year's expenses the sum of $16,000 was provided, and there remained unexpended January 1, $2,400.

Executive Committee: Eight meetings were held. The principal business of most of these meetings was the preliminary study of matters to be brought before Engineering Council so as to economize time at Council meetings.

January 6, 1919, an urgent meeting was called to determine what action Engineering Council could take concerning the sudden dismissal, by the Public Service Commission for the first District of New York, of approximately 350 engineers and assistants engaged on subway construction. (see March PROCEEDINGS).

January 28 a meeting was held to instruct Council's Washington representative as to his course of action before committees of Congress on matters demanding immediate attention, especially propositions relating to a National Department of Public Works.

Rules Committee: Prepared and submitted for adoption at the February meeting, 1918. "Rules for Guidance of Business" and "Rules for Admission of Additional Societies to Membership in Engineering Council." The latter rules were subsequently duly aproved by United Engineering Society and the four Founder Societies. A tentative list of societies eligible for membership was prepared and sent to all representatives. From this list six societies were selected for immediate consideration and three ultimately elected, subject to approval by United Engineering Society and the Founder Societies. These approvals were all received by December 1918.

Public Affairs Committee: This committee made preliminary investigations which led to the appointment of a Patents Committee and a Committee on Licensing of Engineers. It presented a resolution to the December meeting of Council, requesting favorable attention of Congress to land reclamation on a large scale as a "reconstruction" measure under thorough engineering supervision. This resolution was adopted by Council and later followed up by the Washington representative. The committee also reported upon the allocation of labor and equipment for production of war materials, an "Institute for

History of Science" as a branch of the Patent Office, engineering experiment stations at Land Grant Colleges, assistance to members of faculties of colleges of pure and applied science engaged on war work by relieving them of certain routine duties; no activity was undertaken by Council in any of these matters.

American Engineering Service: Devoted its energies and those of its small staff, almost exclusively to aiding governmental departments in procuring technical men for war service. With the assistance of the four Founder Societies and other engineering societies, classified records of many thousands of engineers were assembled and from these, in response chiefly to more than two hundred requisitions from thirty principal and subordinate governmental departments, names of approximately four thousand engineers were supplied, all carefully selected. Many interviews between Army and Navy officers and candidates were arranged and other services rendered. Besides, a number of engineers were assisted in finding engagements in civilian work and several offices were aided in obtaining engineers. This committee was disbanded at the end of November on account of the armistice and was succeeded by Engineering Societies Employment Bureau.

War Committee of Technical Societies: The committee had 22 members representing 11 societies. Financial support was provided by Engineering Council. The Naval Consulting Board provided offices in New York, and for the last few months also in Washington, together with frank for mail and other assistance. This committee was closely allied with the Naval Consulting Board, and, beginning in the summer of 1918, also with the Inventions Section of the Army General Staff: the latter provided the services of Capt. Scott as secretary. On account of the armistice, this committee ceased to exist December 31. During the year this committee aided the Army and Navy in examining 135,000 inventions and suggestions for war devices. To stimulate intelligent solution of war problems, the committee with the naval Consulting Board issued two pamphlets, the first entitled "The Enemy Submarine" and the second "Problems of Airplane Improvement." Before the bulletins were issued 0.4 per cent only of suggestions received had any value; afterwards 4.7 per cent. One of the most important services rendered was to demonstrate to the War and Navy Departments how the civilian engineers of the country could be mobilized for the aid of the Government in war, and to establish direct communication for this purpose between the departments named and the engineering societies.

Fuel Conservation Committee: This committee has collaborated with the Bureau of Mines and the Fuel Administration, one of its members being Advisory Engineer to the latter, and its Secretary, Chief Mechanical Engineer to the former. This committee also cooperated with committees of various engineering societies, working along similar lines in many parts of the country. Its work will be continued.

Patents Committee: Appointed so that Engineering Council might have a share in endeavors to improve Patent law practise and the organization of the Patent Office. This committee interlocked with a similar committee of National Research Council and accepted the able report of the latter. This report, recently made public, proposes the following changes in the Patent system:

1. Establishment of a single Court of Patent Appeals;
2. Separation of Patent Office from Department of Interior;
3. Increase in force and salaries of Patent Office;
4. Modification of that section of the law granting compensation for infringment of patents.

Water Conservation Committee: Was created to deal with questions concerning the utilization and control of water for various purposes in all parts of the country. It has defined its general policies and is prepared to furnish broad information on large problems, particularly to committees of Congress, to State Legislatures, or to governmental departments. The committee proposes to deal with those facts of engineering which are beyond reasonable controversy.

Engineering Societies Employment Bureau: Following the termination of hostilities, Engineering Council at its special meeting November 21, established an Employment Bureau with the secretaries of the Founder Societies as a Board of Directors. The Bureau took over the staff and equipment of American Engineering Service at the end of November. From the beginning of its work to February 15, it has received applications for positions from 1375 engineers in all branches of the profession. For a total of 200 applicants, employment has been found. The services of the Bureau are not restricted to members of the engineering societies represented in Engineering Council, but non-members are expected to present letters of introduction from a member. Extensive efforts have been made to inform employers of engineers of the Bureau's resources for serving them. No charge is made for services.

Reconstruction Committee: At the November meeting of Council, in order to deal with several matters falling under the head of "reconstruction" and especially to work out the details of the organization and personnel of the proposed National Service Committee, the Reconstruction Committee was appointed. At meetings held November 29 and December 16, 1918, it selected the personnel of the National Service Committee and determined sufficient elements in its organization to permit that committee to begin work before the end of the year. It was understood that the chairman should be the executive head of the National Service Committee with reasonable independence in action for the effective performance of his duties, and that the other members of the committee would be expected to serve principally in the capacity of an advisory board to the chairman. January 28, the Reconstruction Committee held a joint meeting with members of the Public Affairs and National Service Committees to discuss the establishment of a National Department of Public Works.

National Service Committee: At the November meeting of Council, representative Philip N. Moore presented a communication entitled "Representation of Engineers at National Capital." From this proposal grew the National Service Committee with a permanent representative and office in Washington which was established through the agency of the Reconstruction Committee. The office is Room 502, McLachlen Bldg., 10th and G. Streets, Washington, D. C. The committee has taken up a number of subjects with committees of Congress and the departments. Most important among these have been (1) Land Reclamation, following resolution adopted by Council November 21, (Byrnes Bill S. 13651, proposing an appropriation of $100,000,000 for reclamation of arid, swamp and stump lands); (2) National Public Works Department in connection with Kenyon Bill, S. 5397, and hearings before Committee on Education and Labor to which this bill was referred, and the Committee on Public Buildings and Grounds which was investigating certain work of the Army Construction Division.

License Committee: There is active interest in several states in proposed legislation relating to the licensing of engineers, and a number of inquiries from engineering societies have been referred to this committee. The License Committee is endeavoring to coordinate and direct these activities.

Americanization Committee: Is prepared to co-operate with the Division of Americanization in the Department of Interior, and with the National Americanization Committee. Since engineers have more or less direct contact with large bodies of foreign born employees, it is expected that they will render substantial help in this important work. An instructive report has been written by the committee summarizing the present status of Americanization activities.

Publicity Committee: Is a committee of volunteers to help the Secretary in some of the publicity work, principally in preparing and distributing material for publication in technical journals and daily newspapers after authorization by Council. Besides this New York committee, there are twenty-six correspondents in engineering centers scattered over the country to aid in the transmission of information between Engineering Council's office and local societies of engineers.

American Academy of Engineers: Organizers of the proposed Academy sought the support of Engineering Council in securing a charter from the Federal Government. After several conferences and mature deliberation, Engineering Council declined to support the bill before the House of Representatives

Classification and Compensation of Engineers in Railroad and Government Employment: A communication prepared by Engineering Council addressed to the Railroad Wage Commission was presented by the Secretary in person, to a meeting of that Commission in Washington, February 25, 1918. This matter was pursued from time to time, and with that of the compensation of engineers in Government employment is now in the hands of the Public Affairs Committee.

Reconstruction: Under date of November 15, a letter was sent to President Wilson regarding the appointment of engineers on the proposed Federal Reconstruction Commission. To this letter the President replied briefly under date of November 20, that existing instrumentalities were being utilized. Letters to the governors of all states, urging the inclusion of engineers in any reconstruction commissions which might be appointed, were sent out in February 1919.

Field of Activity of Engineering Council was outlined at the November meeting by carefully prepared preambles and resolutions which have been generally announced to engineering societies. (See January, 1919 PROCEEDINGS).

Information to Federal and State Authorities: At its November meeting, Engineering Council expressed its attitude in the following resolution: "That Engineering Council should be prepared to furnish to Federal and State authorities information regarding engineering and allied facts and opinions which are beyond the field of controversy, and shall take such steps as are consistent with the standing of the societies it represents to inform such Federal and State authorities of its willingness so to act."

Smith-Howard Bill for the establishment of engineering and industrial research stations at educational institutions in all the states was discussed at length. While favoring research when properly carried on, Engineering Council refrained from expressing opinion on the proposed legislation in the form in which it was brought to its attention. Council's Washington representatiye was directed to attend a meeting January 6, of delegates from organizations interested in re-drafting the Smith-Howard Bill; a report of this conference was submitted. The parties interested are still widely at variance and there is nothing further for Council to do at present.

Curricula of Engineering Schools. The subject of changes in curricula of engineering schools was discussed in a general way at more than one meeting. It was brought formally to the attention of Council by resolutions adopted by the War Committee of Technical Societies at its final meeting, suggesting that as a measure of future military preparedness engineer students in the large universities and colleges should receive instruction in the art of war. A committee was appointed December 19 to study this matter: This committee has reported.

Council's second year has been one of creditable activity and achievement and it enters its third year stronger and better prepared for larger service.

UNITED ENGINEERING SOCIETIES' LIBRARY REPORT FOR 1918

The annual report of the Library Board of the Engineering Societies' Library for 1918 has recently been issued, from which the following items have been abstracted.

Books: During 1918 the library received by gift 16,258 books and pamphlets, and by purchase 663 books and pamphlets, making on December 31, 1918, the total resources of the library 157,795 publications of which, 135,829 were accessioned, and 21,903 unaccessioned, the latter item including duplicates and unexamined publications.

The most notable of these gifts have been described in the PROCEEDINGS for July, 1918.

At the beginning of the year, the Library Board, in order to distribute the expense for current periodicals equitably among the Founder Societies, adopted the plan of reimbursing each of them at a uniform price, for copies of its publications sent in exchange for the benefit of the Library.

The purchases have consisted of these periodicals and those obtained by ordinary subscriptions, foreign books and some domestic books which could not be obtained as gifts.

Every effort has been made to obtain, by gift or purchase, all important new publications in America, and also to cover the foreign field as thoroughly as the remaining funds and war conditions would permit. The current trade bibliographies of America, England and France have been examined regularly, and the book reviews in current magazines have also been watched. It is believed that no books of importance, published in these countries during the year, have escaped consideration in the selection of the works to be added to the collection.

GENERAL WORK WITH THE PUBLIC

Attendance and Use of Books: The number of visitors during the year was 15,063 and the following figures show the comparative attendance in other years: 1915—12,820, 1916—13,848, 1917—11,371.

The library was open 302 days, and the average daily attendance was 50 persons. The attendance after six o'clock was 19 per cent of the total. The usual hours were from nine a. m. to ten p. m., but an exception was made during July and August, when the Library was closed at six p. m.

Telephone Service: As indicating the demands made by non-visitors, an incomplete record of telephone inquiries shows that over 1500 inquiries have been received in this way. Each of these required attention by an assistant and, in most cases, the consultation of the catalog or of books. The total time spent in attending to these queries is sufficient to call for consideration in estimating the duties performed by the reference attendants, while the persons who receive help in this way form an important addition to those who visit the reading room.

Mail Service: In addition to the mail handled through the Service Bureau, the Library is constantly in receipt of letters asking for information that can be given without extensive investigation No accurate record is kept of these inquiries, several of which arrive each day. During the year approximately 900 have been answered.

SERVICE BUREAU

The most important item to report is that the earnings of the Bureau for the year exceeded its expenses. The work billed to clients amounted to $9,722.46, the expense for labor and supplies to $8,013.14. The net cash receipts during the year were $8,599 66, of which $8,217.96 was for work done during 1918. In addition the Bureau gave to the National Research Council, the Naval Consulting Board and various other organizations assisting the military activities of the country, work which would have cost several hundred dollars, had it been charged at current rates.

The total number of searches made was 508. To an even greater extent than in 1917, the work of the Bureau dealt with the war activities of the country. Work was done for almost every technical bureau of the government, and the Bureau has also been used by the representatives of many of the Allies.

Seventy-eight translations, amounting to 258,080 words, were made, the figures for 1917 being 59 translations of 349,320 words.

Orders for photographic copies, 1150 in number, called for 6306 prints. This is a decided increase over 1917, when 791 orders for 1342 prints were received.

There has been little change in the subscriptions for current card reference service. The number at the end of the year was 53.

A circular describing briefly the assistance offered through the Bureau was printed at the beginning of the year. Over 30,000 copies have been distributed to members of the Founder Societies.

TECHNICAL WORK AND PROCESSES

The work of accessioning and cataloging the Library has been hampered by a number of unavoidable causes. In addition to the fact that the number of employees has been too small to attend the reference desk and have sufficient time left to carry on the other library work properly, there have been frequent interruptions to the regular progress of affairs through the resignation of employees.

As it has not been possible to catalog all the accessions of the year, the books of greatest importance and those most in demand have been given the preference. All of these have been cared for. It is to be regretted however, that it has not been feasible to undertake a thorough revision of the entire catalog. Such a revision would establish the library upon a firm foundation, improve the service, and reduce the cost of attending to readers by lessening the time and individual attention which must be given to them. We hope that sufficient funds for this work may be provided within the near future.

By using cards printed by the Library of Congress, thus utilizing the expert bibliographic skill of its staff, the labor of our catalogers have been conserved for work on our special problems.

PHYSICAL CHANGES

The fourteenth floor was ready for use at the beginning of the year, and was occupied at once, the periodicals and the library of the American Society of Civil Engineers being transferred to it. This left approximately one-half of the twelfth floor vacant, and this vacant space was delivered to the Founder Societies for store rooms.

Although it has been expected that the shelving provided would meet the needs for four or five years, the unusual gifts have absorbed it rapidly, and the provision of more shelving must soon be undertaken. Sufficient space for this is available.

No additions have been made to the furniture of the Library, it having seemed best to postpone purchases until business conditions were more favorable.

STAFF

The staff at the end of the year numbers 16, exclusive of the Director. There have been a number of changes during the year, several members having resigned to accept better paid positions, and two having been inducted into the army.

The present staff is giving intelligent, conscientious service of a high character, to which it is a pleasure to call attention.

ENGINEERING INDEX

Among the plans for increasing the usefulness of the Library, the publication of an index to current literature has always been foremost. Unfortunately, the Founder Societies again feel unable to contribute the necessary funds for this purpose, and it will be impossible to proceed upon a systematic plan during 1919, unless the expenses can be met from some source as yet unknown.

Although we have been unable to undertake the work, its importance has not been forgotten. The subject has been discussed frequently at meetings and has been considered by a committee appointed for the purpose.

Three Founder Societies are now publishing indexes, viz; The American Society of Civil Engineers, The American Institute of Mining Engineers and The American Society of Mechanical Engineers. The first and last of these are compiled by the respective societies, the remaining one by the Service Bureau. A committee is now considering the possibility of consolidating the preparation of two or more of these, under the direction of the Library. Such a consolidation of effort would permit the field to be covered more carefully without increased expense, would tend to standardize the methods used and would form an important step toward the realization of a complete, permanently established index. By some such arrangement it is hoped that the time until the Library is able to have a definite budget for indexing can be tided over without failing to make use of its great possibilities in this direction. The need is one universally recognized by engineers.

FINANCIAL STATEMENT 1918

LIBRARY MAINTENANCE

REVENUE		
Founder Society Contributions	$16,000.00	
Library endowment income	5,000.00	
Total Library appropriation		$21,000.00
EXPENDITURES		
Salaries	$15,137.59	
Books and binding	3,906.13	
Supplies and Misc. expenditures	1,505.78	
Equipment	120.00	
Total expenditures		$20,669.50
Excess of appropriation over expenditures		$330.50

SERVICE BUREAU

EARNINGS		
Cash received	$8,217.96	
Outstanding bills	1,504.50	
Total gross earnings as charged on books		$9,722.45
EXPENDITURES		
Salaries	$6,575.24	
Supplies	1,437.90	
Total expenditures		$8,013.14
Net Earnings		$1,709.32
CASH STATEMENT		
Cash received		$8,813.30
On account due depositors		213.64
Net cash receipts		$8,599.66

PAST SECTION MEETINGS

Baltimore.—February 14, 1919, Engineers' Club. Paper: "Electrical Communications in War Times" by E. B. Craft. Paper illustrated with lantern slides. Joint meeting with local sections of Civil, Mechanical and Chemical Engineers, and the Engineers' Club. Attendance 110.

Chicago.—February 24, 1919, Western Society of Engineers' Rooms. Illustrated address by Mr. John B. Taylor on "Accoustical Engineering." Attendance 200.

March 14, 1919. Special meeting to discuss various problems to be taken up by Committee on Development. Attendance 35.

Cleveland.—February 17, 1919, Electrical League. Illustrated address by Mr. H. L. Bradley on "The Development of Carbon Pile Rheostat for Battery Charging and Motor Control." Attendance 49.

Detroit—Ann Arbor.—February 28, 1919, Detroit Board of Commerce. Paper: "Alternating Current Generators" by Prof. John C. Parker. Attendance 61.

Fort Wayne.—March 7, 1919, G. E. Assembly Room. Lecture by Major Darnell on "The X-Ray and Its Application to War Uses." Attendance 125.

Indianapolis —Lafayette.— February 11, 1919, Athenaeum. Papers: (1) "Trench Warfare Ammunition" by Lieut. B. P. Lyons; (2) "Development in Signal Corps Apparatus during the War" by Emerson Pugh. Attendance 42.

Ithaca.—February 7, 1919, Franklin Hall, Cornell University. Illustrated lectures as follows— (1) "Airplane Performance" by Prof. Frederick Bedell; (2) "Some Recent Developments in Radio Communication" by Prof. W. C. Ballard. Attendance 200.

Los Angeles.—February 25, 1919, Edison Assembly Hall. Papers by Messrs. J. N. Kelman and Carl Johnson on "The Future of Electrical Manufacturing in Southern California." Brief address by Mr. Paul M. Lincoln on "The Work of the Development Committee." Attendance 39.

Lynn.—March 5, 1919, General Electric Hall. Illustrated lecture by Mr. L. E. Underwood on "Machine Guns and Their Development." Attendance 165.

Milwaukee.—February 19, 1919, Milwaukee Athletic Club. Addresses as follows—"Activity of the Engineer in Civic Affairs" by William Bruce; "The Method of Assembling Steel Ships" by George Newton. Attendance 135.

Minnesota.—January 30, 1919, University of Minnesota. Paper: "Electric Furnaces" by L. H. Berry. Attendance 115.

Panama.—January 26, 1919, Balboa Heights. Paper: "The Uses of the Telephone Repeater in Long Distance Transmission" by J. T. Thibault. Attendance 32.

February 22nd, 1919. Annual outing and beach party at Taboga Island, and dinner at Hotel Aspinwall. Attendance 60.

Philadelphia.—February 10, 1919, Engineers' Club. Illustrated lecture by Dr. Joseph W. Richards on "The Importance of the Electrochemical Industry." Attendance 90.

March 10, 1919, Engineers' Club. Illustrated lecture by Lieut. Col. J. W. Hubbell on "Field Communication, 1st Army Corps, A. E. F." Attendance 190.

Pittsfield.—February 14, 1919, New American Hotel. Illustrated lecture by Dr. Ellwood B. Spear on "Problems of Gas Warfare." Attendance 125.

February 27, 1919, Masonic Temple. "A Trip to California," lecture and pictures by Mr. John B. Crum of U. S. Railroad Administration. Attendance 675.

Saint Louis.—February 26, 1919, Engineers' Club. Paper: The Development of the Electric Furnace" by W. E. Moore, presented by Mr. G. A. Waters. Attendance 72.

San Francisco.—February 7, 1919, Engineers' Club. Paper: "Unification of Manual and Automatic Telephone Systems at Los Angeles" by B. E. Wiseman. Attendance 65.

Schenectady.—February 28, 1919, Edison Club Hall. Subject: "Automatic Generating Stations and Substations." Speakers: Messrs. H. R. Summerhayes, C. M. Davis, L. B. Bonnett, A. G. Darling, C. M. Hackett. Attendance 300.

March 7, 1919, Edison Club Hall. Illustrated lecture by Dr. C. P. Steinmetz on "Soap Bubbles." Attendance 294.

Seattle.—February 18, 1919, Arctic Club. Paper: "The X-Ray" by Mr. Coward. Discussion by Dr. C. E. Magnusson, and Messrs. G. E. Quinan and J. D. Ross. Attendance 30.

Spokane.—February 21, 1919, Chamber of Commerce. Paper: "A Plan for the Development of Our National Power Resources" by C. E. Magnusson. Attendance 49.

Toronto.—February 21, 1919, Engineers' Club. Paper: "The Business Relations of the Engineer" by Frank R. Ewart. Attendance 50.

March 7, 1919, Engineers' Club. There was a general discussion on "The Future Organization of Electrical Engineers in Canada." Attendance 45.

Urbana.—February 26, 1919, University of Illinois. Paper: "The Measurement of Small Alternating Current by Means of an Acoustical Resonator" by Dr. F. R. Watson. Attendance 25.

Washington.—March 11, 1919, Cosmos Club. Illustrated address by Mr. C. A. Kelsey on "The Manufacture of Sugar." Attendance 142.

PAST BRANCH MEETINGS

University of Arkansas.—March 6, 1919. Address by Dr. Harrison Hale on "The Opportunities of the Engineer of Today." Attendance 32.

Armour Institute.—February 20, 1919, Electrical Lecture Room. Illustrated lecture by Mr. Charles H. Jones on "Automatic Substations." Attendance 30.

March 13, 1919. Illustrated lecture on "The Message of the Curtis Steam Turbine." Attendance 24.

Carnegie Institute of Technology.—March 12, 1919, Machinery Hall. Illustrated address as follows—(1) "Glimpses of France from the Airplane" by Lieut. G. L. Tillbrook; (2) "In France with the Engineers" by Lieut. J. H. Waxman. Election of Mr. H. C. Nordfeldt as secretary to fill vacancy caused by resignation of Mr. E. F. Shumway. Attendance 30.

University of Cincinnati.—February 28, 1919, Engineering Building. Paper: "Automatic Fuse Testing at the National Cash Register Company's Plant" by Earl Flatt. Attendance 43.

March 13, 1919, Engineering Building. Address on "Some of the Work being done by Means of the Oscillograph at the University of Cincinnati." Attendance 41.

University of Colorado.—February 21, 1919. Mr. H. H. Kerr spoke on "The Construction of the Lacombe Plant of the Denver Gas and Electric Company." Attendance 25.

University of Maine.—March 5, 1919. Address by Mr. Davis on "The System of the Bangor Railway and Electric Company." Mr. F. A. Tracy gave a talk on his work during the summer. Attendance 36.

Massachusetts Institute of Technology.—January 22, 1919. Paper: "Mechanical Analogies of Electrical Phenomena" by Prof. W. S. Franklin. Attendance 70.

February 5, 1919. Paper: "Labor Conditions in America After the War" by N. H. Daniels. Attendance 100.

March 7, 1919. Illustrated lecture on the "Edison Distribution System" by L. L. Elden. Attendance 36.

University of Minnesota.—March 5, 1919, Engineering Auditorium. Addresses as follows—(1) "Illumination" by Prof. Shepardson; (2) "Manufacture of Incandescent Lamps" by Mr. Petty. Attendance 43.

University of Missouri.—February 17, 1919, Engineering Building. Paper: "Electrical Machinery for Coal Mines" by L. P. Van Houten. Attendance 23.

March 3, 1919, Engineering Building. Papers: (1) "Limitations of High Tension Transmission" by G. B. Cox; (2) "Water Power Conservation" by R. C. Morris. Attendance 20.

University of Nebraska.—March 6, 1919, Electrical Engineering Building. Illustrated address by Mr. O. P. Reed on "The Use of the Audion Tube in Radio Work." Attendance 48.

Ohio Northern University.—February 20, 1919, Dukes Memorial. Papers: (1) "High Voltage Transmission" by C. K. South; (2) "Telephones" by W. L. Lynde. Attendance 12.

Ohio State University.—February 21, 1919, Robinson Laboratory. Papers: (1) "Experiences in the Air Service and Light Artillery" by Lieut. C. E. Shilling; (2) "Automatic Substations and Their

Control" by H. E. Lockett. Attendance 15.

Purdue University.—February 18, 1919, Electrical Building. Illustrated address by Mr. K. B. McEachron on "The Experimental Laboratory Method to Meet the Demand of Nitrates Since the War." Attendance 85.

Throop College of Technology.—February 24, 1919. Address by Mr. Ford W. Harris on "Patents and Patent Laws." Attendance 200.

March 3, 1919. Address by Mr. Paul M. Lincoln on "Modern High Tension Transmission." Attendance 200.

State College of Washington.—March 7, 1919, Mechanic Arts Building. Paper: "The Nine Mile Power Plant" by G. Bodwell. Election of officers as follows—chairman, Joseph L. Williams; vice-chairman, Nelson E. Lytle; secretary, Glen G. Langdon; treasurer, H. C. Vance; reporter, I. W. Vander Heyden. Attendance 26.

University of Washington.—March 4, 1919, Forestry Building. Paper: "Commercial Radio Sets" by A. C. Miller. Attendance 12.

ASSOCIATES ELECTED MARCH 14, 1919

*ABBOTT, AMOS H., Staff Engineer, St. Paul Gas Light Co., St. Paul, Minn.

ABRAHAMS, SAMUEL LIONEL, Production Engineer, General Electric Co., Lynn; res., 223 Harvard Ave., Allston, Mass.

ALMQUIST, FRANK G., Vice-President & Treasurer, Lockwood & Almquist, Inc., 112 E. 19th St., New York, N.Y.

*BAKKE, THROAN T., Asst. Foreman, Testing Dept., General Electric Co., Schenectady, N. Y.

BARRETT, CHARLES F., Chief Electrical Inspector, U. S. A. Base, Q. M. C., 187 Waverly Ave., Brooklyn, N. Y.

BARROWS, L. DWIGHT, Engineering Dept., American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

*BEHR, HERBERT RICHARD, Testing Engineer, Commonwealth Edison Co.; res., 1622 Sherwin Avenue, Chicago, Ill.

BERGER, S. A., Manager, Meter Section, Supply Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

BLIZIOTIS, GEORGE E., Radio Electrician, Westinghouse Elec. & Mfg. Co.; res., 58 Plane St., Newark, N. J.

BODDE, THEODORE, Electrical Engineer, General Electric Co., Lynn; res., Marblehead, Mass.

BRITT, JOSEPH, Inspector, Electrical Engineering Dept., N. Y. Central R. R., Grand Central Terminal, New York, N. Y.

BROADBERRY, WALDIE, Chief Electrician, Harbison Walker Refractories Co., Mount Union, Pa.

BROOKS, HENRY T., Long Line Engineer, Cumberland Tel. & Tel. Co.; res., 1813 Russell St., Nashville, Tenn.

BROOME, WILLIAM GEORGE, Electrician. University of Wisconsin; res., 20 No. Patterson St., Madison, Wis.

BUELL, FRANK TRUMAN, Efficiency Engineer, Western Electric Co., Chicago; res., 646 So. Euclid Ave., Oak Park, Ill.

BULLINGTON, LEE CONE, Asst. to Manager, Power Dept., Westinghouse E. & M. Co., E. Pittsburgh, Pa.

CAMPBELL, FRANCIS CARLYLE, Student Engineer, General Electric Co.; res., 763 Nott St., Schenectady, N. Y.

CANDLISH, BOYD, Sales Engineer, Herbert Morris Crane & Hoist Co., Niagara Falls, Ontario.

CARR, COLIN KENNEDY, Inspector (Steel, Machinery & Elec. Equipment), British War Mission, U. S. S.; res., 3142 Kimball Ave., Toledo, Ohio.

CARR, LAURENCE H. A., Chief Designer, J. H. Holmes & Co., Newcastle-on-Tyne; res., 1 Brighton Grove, Monkseaton, Northumberland, Eng.

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CASAL, FRANCIS MARION, JR., Asst. Engineer, Tel. & Tel. Div., California Railroad Commission, 833 Market St., San Francisco, Cal.

*CLARK, EDWARD L., Test Man, General Electric Co.; res., 143 Lafayette St., Schenectady, N. Y.

Clyde, Wilford W., Electrical Engineer, Spring Canyon Coal Co., Storrs, Carbon Co., Utah.

Cockaday, Laurence Marsham, Asst. Engineer, Elec. Research Laboratory, Habirshaw Electric Cable Co., Yonkers; res., 2674 Bailey Ave., New York, N. Y.

*Cole, Harold, Engineer, Distribution Engineers' Office, The Detroit Edison Co., 1700 David Whitney Bldg., Detroit, Mich.

*Coley, Walter R., Laboratory Foreman, Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia, Pa.

Colien, Francis Edward, Equipment Dept., Bell Telephone Co. of Pa., Johnstown, Pa.

Collier, David C., 2nd Lieut., Aviation Section, Signal Corps, Goldman Field, Stithton, Ky.; res., 3247 Glenwood Ave., Toledo, Ohio.

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De Salis, Harry W., Draftsman, Engineering Dept., Canadian Westinghouse Co.; res., 92 Glendale Ave., Hamilton, Ontario.

Di Cesare, George E. N., Electrical Engineer & Designer, Sperry Gyroscope Co., Manhattan Bridge Plaza, Brooklyn, N. Y.

Dickie, Douglas P., Engineering Assistant, Western Union Tel. Co.; res., 250 West 104th St., New York, N. Y.

Dickinson, John Aaron, Associate Mechanical Engineer, Bureau of Standards, Washington, D. C.

Dontopoulos, John Theodore, Bethlehem Shipbuilding Corp., San Francisco; res., 1018 Jefferson St., Oakland, Cal.

Dooley, John James, Electrical Engineer, 137 Fern Avenue, Lyndhurst, N. J.

Doughty, William E., Engineer, James Vernon Co.; res., 674 Woodrow Ave., Detroit, Mich.

Eggers, Henry C. T., Telephone Engineer, Engg. Dept., American Tel. & Tel. Company, 195 Broadway, New York, N. Y.

Elliott, John Wilson, Asst. Foreman, Testing Dept., Westinghouse Elec. & Mfg. Co.; res., 611 Grandview Ave., E. Pittsburgh, Pa.

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Faram, Samuel Thomas, Supt., Toronto Factory, Benjamin Electric Mfg. Co.; res., 181 Sheldrake Blvd., Toronto, Ont.

Fauquex, Alfred, Elec. Construction Div., Interborough Rapid Transit Co.; res., 154 W. 13th St., New York, N. Y.

Furlong, Thomas Aloysius, Electrical Engineer, Allis-Chalmers Mfg. Co.; res., 342½, 26th Ave., Milwaukee, Wis.

Granfield, Thomas Henry, Engineering Dept., N. W. Tel. Ex. Co.; res., 905 Summit Ave., Minneapolis, Minn.

*Grove, Harry Samuel, Chief Electrician, U. S. S. Fanning; Postmaster, New York, N. Y.

Haas, Richard Edward, Jr., Meter & Test Dept., United Electric Light & Power Co., 514 West 147th St., New York, N. Y.

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Hall, Arthur Grant, Dist. Electrical Inspector, Hydro-Elec. Pr. Comm. of Ontario, Temple Bldg., Toronto, Ont.

Hanley, John F., Electrical Engineer, Fay, Spofford & Thorndike, Boston; res., 7 Bunker Hill St., Lawrence, Mass.

Harris, Perry Lee, Chief Electrician, Federal Shipbuilding Co., Kearny, N. J.

*__Harrison, Henry C.__, Telephone Engineer, Western Electric Co., 463 West St.; res., 277 W. 11th St., New York, N. Y.

Harvey, Henry Franklin, Jr., Switchboard Engineering Dept., General Electric Co.; res., 5 Parkwood Blvd., Schenectady, N. Y.

Healy, Francis C., Engineering Dept., American Tel. & Tel. Co., 195 Broadway; res., 722 St. Nicholas Ave., New York, N. Y.

*__Henline, Henry Harrison__, Instructor in Electrical Engineering, Leland Stanford Jr. University, Stanford University, Cal.

Hodgins, Lawrence Judson, Asst. Prof. of Electrical Engg. & Physics, Maryland State College of Agriculture, College Park, Md.

Holden, Edward Atwill, Field Engineer, Philadelphia Electric Co.; res., 6153 Linekiln Pike, Philadelphia, Pa.

Hotopp, Alfred Henry, Tester, New York Telephone Co., New York, N. Y.; res., 27 Charles St., Jersey City, N. J.

*__Hudspeth, Clarence C.__, Asst. Foreman, Testing Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 506 Jeannette St., Wilkinsburg, Pa.

Jacobus, Charles Roswell, Electrical Engineer, General Electric Co., Newhouse Bldg., Salt Lake City, Utah.

*__James, Frederick Earl__, Student Engineer, Testing Dept., General Electric Co., Witherspoon Bldg., Philadelphia, Pa.

Kalaway, John Andrew, Asst. Foreman, Transformer Dept., Westinghouse Elec. & Mfg. Co., Pittsburgh; res., 7705 Cannon St., Swissvale, Pa.

Kelly, Joseph Bernard, Electrical Engineer, Western Electric Co., 463 West St., New York; res., 541 Chauncey St., Brooklyn, N. Y.

Kerr, Albert Moore, Electrical Draftsman, Firestone Tire & Rubber Co.; res., 267 Firestone Blvd., Akron, Ohio.

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Kjellgren, John Gottfrid, Electrical Engineer, The Electric Railway Improvement Co.; res., 1596 Ansel Road, Cleveland, Ohio.

Knecht, J. George, Wireman (Armature), Motor Repair Shop, The Panama Canal, Balboa, C. Z.

Kuehl, Frederick A., Supervising Inspector, Boston Army Supply Base, Boston; res., 81 Myrtle St., Medford, Mass.

Kuhn, George W., Telephone Engineer, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

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*__Lawson, Harry John__, Supt. of Power, Salt River Valley Water Users Association, Water Users Bldg., Phoenix, Ariz.

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*__Lynn, Clarence__, 1247 Kentucky St., Lawrence, Kansas.

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Miller, J. Albert, Switchboard Operator, Balboa Substation, Panama Canal; res., Ancon, C. Z.

*Miller, John Harold, Designing Engineer on Instruments, Jewell Electrical Instrument Co., Chicago; res., 420 Wisconsin Ave., Oak Park, Ill.

*Moll, Homer I., 2nd Lieut., Signal Corp., U. S. A., Franklin Cantonement, Camp Meade, Md.; res., Strausstown, Pa.

Moore, Henry Ray, Telephone Sales Engineer, Western Electric Co., Hawthorne Station, Chicago; res., Riverside, Ill.

*Moore, James Humphrey, Engineering Dept., American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

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***Sly, Jay A.**, Chief Engineering Clerk, Northwestern Electric Company; res., 587 Yukon Avenue, Portland, Ore.

Smith, Chester Martin, Switchboard Service Manager, Western Electric Co., Chicago; res., 415 7th Ave., La Grange, Ill.

***Smith, Earl Russell**, Engineering Asst., Bell Tel. Co. of Pa., 1230 Arch St., Philadelphia; res., 1074 Berwick St., Easton, Pa.

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Soderholm, Arthur Eric, Supt. of Power Houses & Sub-stations, N. Y. State Railways; res., 332 Garson Ave., Rochester, N. Y.

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Thuener, Otto Christian, Student Engineer, General Elec. Co.; res., R. F. D., No. 7, Schenectady, N. Y.

***Tolmie, Jack Roderick**, Radio Draftsman, Radio Laboratory, Navy Yard, Puget Sound; res., 1213 Columbia St., Seattle, Wash.

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***Tree, Edward Wesley**, Publication Dept., American Society of Mechanical Engineers, New York; res., 61 Porterfield Place, Freeport, N. Y.

Tsumori, Eigoro, Japanese Electrical Engineer, General Electric Co., Schenectady; res., 147 Riverside Ave., Scotia, N. Y.

Van Asperen, Cornelis Hendrik, Asst. Laboratory Engineer, Hydro-Electric Power Comm. of Ontario, Toronto, Ont., Canada.

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***Walther, John T.**, Engineering Dept., Firestone Tire & Rubber Co., Akron, Ohio.

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*WATSON, EDWARD FISK, Engineer, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

WAY, DONALD D., Asst. Electrical Engineer, Singer Mfg. Co., Elizabethport, N. J.; res., 21 Claremont Ave., New York, N. Y.

WEISSINGER, HARRY, Salesman, Lewis & Roth Corp.; res., 2624 N. 31st St., Philadelphia, Pa.

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*YAMADA, FRED TAKUJI, Graduate Student Apprentice, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., Westinghouse Club, Wilkinsburg, Pa.

YAMAMOTO, SOICHI T., Elec. Engineering Draftsman, The Koppers Co.; res., Hill Top Y. M. C. A., Pittsburgh, Pa.

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YUNGINGER, GEORGE S., Foreman, Machine Shop, Stock Quotation Telegraph Co., 26 Beaver St.; res., 512 E. 88th St., New York, N. Y.

Total 157

*Former enrolled Students

ASSOCIATES RE-ELECTED MARCH 14, 1919

BENSON, MELVIN BERNARD, Benson Electric Company, Superior, Wis.

DRESSNER, VICTOR D., Electrical Asst., Testing Bureau, Brooklyn Rapid Transit Co., 500 Kent Ave., Brooklyn, N. Y.

MAYNARD, CLOYD TABOR, Asst. Electrical Engineer, Rumford Falls Power Co., Rumford, Maine.

O'DONOHOE, JAMES P., Division Elec. Engineer, Postal Telegraph Co., 253 Broadway, New York, N. Y.; res., E. Orange, N. J.

OLNEY, WILLIAM M., Equipment Engineer, New York Telephone Co., Long Island Division; res., 409 Clinton St., Brooklyn, N. Y.

SHERWOOD, WILLIAM RAYMOND, Engineer, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

MEMBERS ELECTED MARCH 14, 1919

BASCOM, HENRY MELVIN, Telephone Engineer, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

*CLARK, ALVA BENSON, Engineering Dept., American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

CLARK, BRIGGS LYMAN, Electrical Division, Bethlehem Shipbuilding Corp.; res., 326 Elmwood Road, Bethlehem, Pa.

COURSER, CHARLES H., Chief Engineer, Texas Gas & Electric Co., 417 Commercial Natl. Bank Bldg., Houston, Texas.

DOHERTY, W. F., Chief Engineer of Generation, Tata Hydro-Electric Power Supply Co., Bombay, India.

FOLK, GEORGE E., General Patent Attorney, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

*HOPKINS, RAYMOND A., Electrical Engineer, Stone & Webster, 147 Milk St., Boston, Mass.

Jacob, Arthur, Engineer, British Aluminum Co. Ltd., London; Director, London Aluminum Co. Ltd., Birmingham, England.

Klopsteg, Paul Ernest, Sales Dept., Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia; res., Glenside, Pa.

Marshall, R. C., Jr., Brigadier-General, Chief of Construction Div., U. S. A.; res., The Farnsboro, Florida & Decatur Sts., N. W., Washington, D. C.

Mills, Nathaniel Child, Designing Engineer, Canadian General Electric Co.; res., 595 Chamberlin St., Peterboro, Ont.

Taylor, Alfred Mills, Major, Air Force, British Army, London, W. C.; res., Slade Lodge, Erdington, Birmingham, England.

TRANSFERRED TO GRADE OF FELLOW, MARCH 14, 1919

Frank, John J., Asst. Engineer, Transformer Dept., General Electric Co., Pittsfield, Mass.

TRANSFERRED TO GRADE OF MEMBER, MARCH 14, 1919

Bush, Vannevar, Consulting Engineer, American Radio & Research Corp., Medford Hillside, Mass.

Coates, William A., Chief Engineer, Detail Dept., British Westinghouse Electric & Mfg. Co. Ltd., Trafford Park, Manchester, England.

Dubilier, William, Consulting Engineer, New York, N. Y.

Harbin, George F., Electrical Engineer, Washington Terminal Co., Washington, D. C.

Scott, Carl F., Manager, Specialty Apparatus Sales, Sprague Electric Works, New York, N. Y.

Simon, Emil J., Radio Engineer, New York, N. Y.

CORRECTION
TRANSFERRED TO GRADE OF MEMBER FEBRUARY 19, 1919

Tappan, Frank Girard, Acting Director of School of Elec. Engg., Supervisor of Vocational Training, Univ. of Oklahoma, Norman, Okla., was transferred to Grade of Member on February 19, 1919 and not elected to that grade as indicated in the Proceedings of March, 1919.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its regular monthly meeting, held on March 10, 1919, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Member

Dobson, William P., Laboratory Engineer, Hydro Electric Power Commission of Ontario, Toronto, Ont.

Merrill, J. L., Power Specialist, Division Ship Yard Plants, Emergency Fleet Corp., Philadelphia, Pa.

Slocum, Winthrop W., Pittsburgh, Pa.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before April 30, 1919.

Anson, R. A., Peterboro, Ont.
Arnold, E. C., Cottonwood Falls, Kans.
Barber, S. H., Elizabeth, N. J.
Barnes, H. B., Denver, Colo.

Barto, L. W., Camden, N. J.
Bawden, C. C., New York, N. Y.
Bauhan, O., Camden, N. J.
Beebe, C. F., Cleveland, Ohio.
Bell, E. C., Wheeling, W. Va.
Bellinger, W. F., Atlanta, Ga.
Berry, C. J., Nela Park, E. Cleveland, O.
Beyerle, W. P., Baltimore, Md.
Bezirjin, V. H., Schenectady, N. Y.
Biedler, W. T., Baltimore, Md.
Bowne, G. D., Jr., Boston, Mass.
Boyer, J. M., Baltimore, Md.
Brame, A. H., Washington, D. C.
Brandt, A., Oakland, Cal.
Bremilst, A. F., Roxbury, Mass.
Brier, W., Seattle, Wash.
Brunson, W. E., Jr., Auburn, Ala.
Buck, N. E., Chicago, Ill.
Burke, E. C., Schenectady, N. Y.
Burley, W. B., Minneapolis, Minn.
Burton, H. J., (Member), Jackson, Mich.
Cameron, D. H., N. Sydney, Nova Scotia, Can.
Checco, C. H., Pittsburgh, Pa.
Chestnut, R. W., Waynoka, Okla.
Clark, J. A., Newark, N. J.
Clay, H. C., Trenton, N. J.
Clem, J. E., Pittsfield, Mass.
Clements, L. J., Portland, Ore.
Cobb, D. B., New Haven, Conn.
Coelho, R., New York, N. Y.
Cole, H. T., Boston, Mass.
Cole, O. R., San Francisco, Cal.
Collins, E. W., St. Louis, Mo.
Connolly, L. P., St. Louis, Mo.
Conover, J. W., Washington, D. C.
Cooley, C. H., Bethlehem, Pa.
Cravens, W. H., Washington, D. C.
Crowther, C. W. W., Shawinigan Falls, Que.
Crumley, T. R., New York, N. Y.
Culliford, S., Boston, Mass.
Cunningham, F. J., (Member), Jackson, Mich.
Davis, A. P., New York, N. Y.
Deutsche, E. I., (Member), Milwaukee, Wis.
Dickinson, C. R., New York, N. Y.
Dickinson, J. P., Binghamton, N. Y.
Dowling, H. O., E. Pittsburgh, Pa.
Drumm, R. E., Philadelphia, Pa.
Dunlap, E. F., Portland, Ore.
Easter, J. W., Baltimore, Md.
Eaton, W. R., Cambridge, Mass.
Edson, W. E., Baltimore, Md.
Eisenhofer, S. L., Toronto, Ont.
Ely, G. G., (Member), Rochester, N. Y.
Fielder, A. H., Peterborough, Ont.
Foote, B. R., Hartford, Conn.
Fraser, C. E., Brooklyn, N. Y.
Freeman H. F., New York, N. Y.
Funk, W. H., New York, N. Y.
Galleth, V. W., New York, N. Y.
Gentsch, H. S., Philadelphia, Pa.
Gilbart, W. H., (Fellow), Fairfield, Ala.
Gilman, G. W., Peterboro, Ont.
Goad, C. E., Toronto, Ont.
Gray, W. H., Trenton, N. J.
Griffen, E. B., New York, N. Y.
Griffeth, C. L., Schenectady, N. Y.
Grimes, W. F., Washington, D. C.
Gronvold, I. J., Tacoma, Wash.
Gurtner, A. H., Hoboken, N. J.
Haas, P. G., Medway, Mass.
Hamilton, G. W., Chicago, Ill.
Harbecke, H. H., Chicago, Ill.
Harrison, L. S., (Member), New York, N. Y.
Hattrick, E., Denver, Colo.
Hay, W. J., Pittsburgh, Pa.
Heller, J. E., San Francisco, Cal.
Henkle, J. C., Portland, Ore.
Hensgen, W. O., Schenectady, N. Y.
Hinson, N. B., Los Angeles, Cal.
Holmgren, E. L., Peterboro, Ont.
Holmstrom, F. Jr., (Member), Chicago, Ill.
Horne, A. A., (Member), Saltville, Va.
Houck, R. L., Portland, Ore.
Howard, A. S., Washington, D. C.
Hubbard, F., Baltimore, Md.
Hulse, L. R., (Member), Newport News, Va.
Hultgren, C. D., Topeka, Kans.
Hunt, J. V., E. Pittsburgh, Pa.
Hussey, R. M., Woodlawn, Pa.
Jacob, H. G., Toronto, Ont.
Jolliffe, O. P., Schenectady, N. Y.
Jones, S. M., St. Louis, Mo.
Keeler, O. E., New York, N. Y.
Kelly, F. W., Ft. Wayne, Ind.
Keesling, H. G., Oakland, Cal.
Keilholtz, L. S., (Fellow), Dayton, O.
Koch, R. W., Denver, Colo.
Korik, C., S. Bethlehem, Pa.
Kreger, C. H., Chicago, Ill.
Kuehn, C. A., Cleveland, Ohio.

Laganke, W. E., Cleveland, Ohio.
Laine, F., San Francisco, Cal.
Lankford, C. H., St. Louis, Mo.
Lee, S. T., Yankton, So. Dak.
Leibing, J. K.,(Member), Newark, N. J.
Lowe, H. C., Boston, Mass.
Lucas, R. A., Philadelphia, Pa.
Lynch, A. W., Philadelphia, Pa.
Macias, C., Mexico D. F., Mex.
Mack, C. T., Toledo, Ol
MacLaren, F. B., Philadelphia, Pa.
Mahard, E. P., Natick, Mass.
Maillard, A. L., (Member), Harrisburg, Pa.
Maltman, J. S., Baltimore, Md.
Mann, J. T., New York, N. Y.
Manwaring, M., Murray, Utah.
McAllister, G. M., E. Cleveland, Ohio.
McCarthy, C. C., Washington, D. C.
McClung, D. R., Portland, Ore.
McDonnell, J. H., Muscle Shoals, Ala.
McElroy, G., New York, N. Y.
Meyer, H. C. A., Baltimore, Md.
Mills, T. C., Keokuk, Iowa
Minard, C. W., King Ferry, N. Y.
Newcomb, T., Troy, N. Y.
Newell, F. R., Salt Lake City, Utah.
Noss, M. A., New York, N. Y.
Nosworthy, F., (Member), San Francisco, Cal.
Orr, R. E., (Member), Los Angeles, Cal.
Oseroff, D. M., Hog Island, Pa,
Patterson, J. D., Peterboro, Ont.
Pease, W. F., Lowell, Wis.
Peterman, L. C., Cleveland, Ohio.
Pfisterer, F. M., Baltimore, Md.
Power, H. J., Medford Hillside, Mass.
Pumphrey, E. L., Washington, D. C.
Purdy, C. H., Springfield, Ohio.
Putnam, K. C., New York, N. Y.
Redsell, J., Toronto, Ont.
Reich, R. R., Easton, Pa.
Reid, E. A., Urbana, Ill.
Richards, H. A., St. Louis, Mo.
Robbins, C. W., (Member), Chicago, Ill.
Robinson, W. H., Spokane, Wash.
Russell, R. J., St. Louis, Mo.
Sackett, F. V., (Member), New York, N. Y.
Sandin, J., Pittsburgh, Pa.
Schwartz, E. L., Atlanta, Ga.
Scott, LeR. E., Union City, Conn.
Seelye, H. P., Detroit, Mich.
Shubart, B., Denver, Colo.
Sidle, W. P., New York, N. Y.
Sisson, C. E., Peterboro, Ont.
Smith, A. Q., Hog Island, Pa.
Smith, C. I., Medford Hillside, Mass.
Staford, R. H., North Bay, Ont.
Stangebye, H., Chicago, Ill.
Stark, F., Baltimore, Md.
Steinel, C. J., Los Angeles, Cal.
Steiner, H. A., St. Louis, Mo.
Stemler, E. J., New York, N. Y.
Stewart, T. J., Baltimore, Md.
Stoll, C. J., Baltimore, Md.
Stone, E. C., (Member), Pittsburgh, Pa.
Strebig, C. F., Philadelphia, Pa.
Stroud, S., Toronto, Ont.
Swisher, C. L., Rapid City, S. Dak.
Teague, W. I., San Francisco, Cal.
Touriansky, G. I., Hog Island, Pa.
Towles, E. E., Camp Meade, Md.
Tucker, F., Baltimore, Md.
Twining, G. E., New York, N. Y.
Vetter, J. C., Trenton, N. J.
Vinal, G. W., (Member), Washington, D. C.
Wagner, W. H., Chicago, Ill.
Waldinger, H., New York, N. Y.
Weaver, L. E., Newaygo, Mich.
Welsh, J. T., Philadelphia, Pa.
West, J. W., Jr., Richmond, Va.
Whitwright, R. S., Akron, Ohio.
Wilbraham, F. M., Hartford, Conn.
Williams, F. A., Boston, Mass.
Winders, F. R., Madison, Wis.
Woodhull, S. T., Medford, Mass.
Workman, F. E., Cleveland, Ohio.
Zube, H. E., Lorain, Ohio.

Total 190

Foreign Applications

Dwelle, E. C., Balboa, C. Z.
Guimaraes, A. de S. M., Rio de Janeiro, Brazil.
Jobim, A. de C., Rio de Janiero, Brazil.
Metzger, I. W., Criztobal, C. Z.
Nakasawa, G. K., Shimotsuke, Japan.
Salmay, S. H., Panama City, R. P.
Umar, S. M., Bhopal, C. I., India.

Total 7

STUDENTS ENROLLED MARCH 14, 1919

10009 Bartling, A. W., Univ. of Ill.
10010 Hanson, J. W., Univ. of Ill.
10011 Liebermann, E. H., Univ. of Ill.
10012 Jamison, G. T., Univ. of Ill.
10013 Schlacks, H. V., Univ. of Ill.
10014 Keiffer, L. R., Univ. of Ill.
10015 Schultz, C. W., Univ. of Ill.
10016 Thomas, W. E., Mich. Agr. Coll.
10017 Young, H. G., Univ. of Toronto
10018 Erichson, J. S., 3rd, Univ. of Pa.
10019 Rinehart, R. D., Tri-State Coll.
10020 Hill, C. R., Univ. of Toronto
10021 Pund, E. E., Ga. School of Tech.
10022 Merriam, F. F., Ga. School of Tech.
10023 Manning, L. J., Ga. School of Tech.
10024 Godard, W. W., Ga. School of Tech.
10025 Dusson, W. W., Ga. School of Tech.
10026 Carr, J. L., Ga. School of Tech.
10027 Baker, A.W., Ga. School of Tech.
10028 Anderson, L. E., Ga. School of Tech.
10029 Carreker, J. F., Ga. School of Tech.
10030 Cobb, H. N., Ga. School of Tech.
10031 Curtis, T. R., Ga. School of Tech.
10032 Davis, H. C., Jr., Ga. School of Tech.
10033 Dickson, H. G., Ga. School of Tech.
10034 Lewin, H.H., Ga. School of Tech.
10035 Wise, R. J., Ga. School of Tech.
10036 Berwick, R. H., Ga. School of Tech.
10037 Boughton, S. P., Ga. School of Tech.
10038 Busch, L. R., Ga. School of Tech.
10039 Conoley, J. J.,Ga.School of Tech.
10040 Heath, J. M.,Jr., Ga. School of Tech.
10041 Herbig, H. F., Ga. School of Tech.
10042 Mann, R. A., Ga. School of Tech.
10043 Newton, R. B., Ga. School of Tech.
10044 Phillips, G. D., Ga. School of Tech.
10045 Smith, B. F., Ga. School of Tech.
10046 Stanfield, J. H., Ga. School of Tech.
10047 White, D. H.,Ga. School of Tech.
10048 Whitner, J. W., Ga. School of Tech.
10049 Rolle, S. D., Drexel Institute
10050 Quiroga, J. S., Univ of Mich.
10051 Glazer, S. I., Univ. of Mich.
10052 Schneider, A. A., School of Engineering of Milwaukee
10053 Waechter, F. A., N. Y. Elec. School
10054 Beall, K. E., Purdue Univ.
10055 Killingsworth, H. T., Jr., Ala. Poly. Inst.
10056 Howard, M. B., Ala. Poly. Inst.
10057 Little, W. M., Ala. Poly. Inst.
10058 Smith, L. T., Jr., Ala. Poly. Inst.
10059 Thomas, J., Ala. Poly. Inst.
10060 Kelly, R. B., Ala. Poly. Inst.
10061 Wright, G. A., Ala. Poly. Inst.
10062 Vaughn, L. C., Ala. Poly. Inst.
10063 Edwards, W. C., Ala. Poly. Inst.
10064 Nadler, S. J., Ala. Poly. Inst.
10065 Duncan, G. W., Jr., Ala. Poly. Inst.
10066 Mattison, G. A., Jr., Ala. Poly. Inst.
10067 Anderson, J. H., Ala. Poly. Inst.
10068 Howard, W. J., Ala. Poly. Inst.
10069 Terry, E. E., Ala. Poly. Inst.
10070 Pierson, S. W., School of Engg. of Milwaukee.
10071 Gabriel, R. F., N. Y. Elec. School
10072 Turner, C. H., Wentworth Inst.
10073 Upp, C. B., Ohio State Univ.
10074 Pipes, P. P., Ohio State Univ.
10075 Pepper, R. J., Ohio State Univ.
10076 Haase, H. M., Ohio State Univ.
10077 Graber, R. P., Ohio State Univ.
10078 Farr, C. L., Ohio State Univ.
10079 Walker, W. J., Ohio State Univ.
10080 Shumaker, R. L., Ohio State Univ.
10081 Sears, C. G., Ohio State Univ.
10082 Myers, D. S., Ohio State Univ.
10083 Park, G. E., Ohio State Univ.
10084 Bish, H. P., Ohio State Univ.
10085 Anderson, L. D., Univ. of Ark.
10086 Cheery, R. B., Univ. of Ark.
10087 Hannah, P. D., Univ. of Ark.
10088 Felsenthal, S. J., Univ. of Ark.

10089 Teague, W. L., Univ. of Ark.
10090 Cantrell, W. M., Univ. of Ark.
10091 Curtiss, E. E., School of Engg. of Milwaukee
10092 Wildes, K. L., New Hampshire State Coll.
10093 Camossa, M., N. Y. Elec. School
10094 Lovdale, C. T., School of Engg. of Milwaukee
10095 Kitchen, W. A., Univ. of Okla.
10096 Shultz, B. F., Univ. of Okla.
10097 Risen, H. J., Univ. of Okla.
10098 Danner, R. F., Univ. of Okla.
10099 de Tarnava, C., Jr., Univ. of Notre Dame
10100 German, J. L., Tri-State Coll.
10101 Kerlin, E. G., Univ. of Va.
10102 Crispelle, K. G., Univ. of Colo.
10103 Hansen, A. A., Univ. of Colo.
10104 Foulk, T. M., Univ of Colo.
10105 Baker, G. R., Jr., Univ. of Colo.
10106 Riecker, H. A., Case School of Applied Science
10107 Smith, A. C., Jr., Case School of Applied Science
10108 Walton, A. K., Case School of Applied Science
10109 Hahn, A. H., Case School of Applied Science
10110 Moore, C. E., Case School of Applied Science
10111 Seddon, J., Univ. of Wash.
10112 Bloomberg, S., Armour Inst. of Tech.
10113 Malpede, D. J., Armour Inst. of Tech.
10114 Miller, W. H., Drexel Inst.
10115 Huth, H. R., Armour Inst of Tech.
10116 Dobestein, S. A., Armour Inst. of Tech.
10117 Greenberg, B. V., Armour Inst. of Tech.
10118 Pearce, W. W., Jr., Armour Inst. of Tech.
10119 O'Rourke, J. J., Armour Inst. of Tech.
10120 Grant, A. Q., Armour Inst. of Tech.
10121 Albee, T. L., Armour Inst. of Tech.
10122 Douglass, W. A., Armour Inst. of Tech.
10123 Grill, M. J., Armour Inst. of Tech.
10124 Sugaman, A., Armour Inst. of Tech.
10125 Miller, K. W., Univ. of Ill.
10126 Caskey, A. D., Univ. of Ill.
10127 Borelli, A., Univ. of Ill.
10128 Van Nest, P. C., Univ. of Ill.
10129 Grainger, W. W., Univ. of Ill.
10130 Barklage, O. F.. Univ. of Ill.
10131 Johnson, W. H., Univ. of Ill.
10132 Reyskey, J. P., Tri-State Coll.
10133 Fukasawa, F. R., Tri-State Coll.
10134 Fitzgerald. T. C., Tri-State Coll.
10135 Oakley, H. D., Syracuse Univ.
10136 Sherman, W., Syracuse Univ.
10137 Mitchell, E. H., Syracuse Univ.
10138 Matteo, F. P.
10139 Shaw, C. H., Syracuse Univ.
10140 Fox, LeR. B., Syracuse Univ.
10141 Loveland, W. W., Syracuse Univ.
10142 Guard, J. R., Syracuse Univ.
10143 Canfield, R. H., Syracuse Univ.
10144 Braga, M. F., Syracuse Univ.
10145 Blumberg, G. M., Syracuse Univ.
10146 Hannon, J. L., Syracuse Univ.
10147 Douglass, R. H., Tri-State Coll.
10148 Rivas, H. M., Univ. of Notre Dame.
10149 Horn, J. M., Stevens Inst. of Tech.
10150 Katz, H. A., Univ. of Cincinnati

Total 142.

PERSONAL

Ralph Elsman has just been elected Vice-President of the Kings County Lighting Company, Brooklyn, N. Y. Mr. Elsman has been General Manager of the Company which office he still retains and his elevation to the Vice-Presidency comes as a recognition of his splendid service for the Company.

Barzillai G. Worth, Vice-President (and formerly electrical engineer) of Walter Kidde & Co., Inc., has been elected Treasurer of the Monmouth Chemical Company and will have charge of the manufacturing and research. This company produces potassium chlorate electrolytically, use-ing processes and apparatus developed by Mr. Worth.

D. W. **Blakeslee**, Electrical Engineer, formerly Asst. Supt. of the Penn. Elec. & Mfg. Co., has, after serving about two years as First Lieutenant, 56th Engineers, A. E. F., returned to his civil occupation with the Jones & Loughlin Steel Co., Pittsburgh, Pa. Mr. Blakeslee while in France did experimental and development work in connection with anti-aircraft searchlights and sound ranging applications. He now makes a speciality of mill and factory lighting and power applications.

OBITUARY

Archie Oakes, Electrical Engineer for the Schwarze Electric Company, Adrian, Michigan, was fatally injured in a street car collision in Detroit on February 25, 1919. Mr. Oakes became an Associate in the Institute in 1914.

Withold Lesniewski, Electrical Engineer, died of influenza at Pittsburgh on October 19, 1918. Mr. Lesniewski at the time of his death was connected with the Russian Mission of Ways of Communication, New York. He was formerly Assistant Power Expert with the Emergency Fleet Corporation at Philadelphia. He was elected an Associate in the Institute in 1918.

James M. Poyner, Electrical Engineer, for ten years connected with the Baltimore office of the General Electric Company died of influenza at Charleston, West Virginia on March 3, 1919. Mr. Poyner was a graduate of Auburn College of Alabama and was a member of the Engineer Club of Baltimore. He was elected an Associate in the Institute in 1916.

James A. MacQueen an associate member of the Institute died of influenza on February 23, 1919 at Winnipeg, Manitoba. At the time of his death Mr. MacQueen was with the Winnipeg Electric Railway Company as electrical draftsman and construction foreman.

ENGINEERING SERVICE BULLETIN

Opportunities.—The Institute, is particularly anxious to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in the Bulletin. The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Services Available.—Under this heading brief announcements (not more than fifty words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office reference files.

Note.—Copy for publication in the Bulletin should reach the Secretary's office not later than the 20th of the month if publication in the following issue is desired. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

OPPORTUNITIES FOR SERVICE

V-494. Power company in Nebraska requires services of young engineer experienced in underground cables and structure. Alternating current. Salary to start about $115. per month. Give age, experience and references.

V-495. Wanted-Branch Sales Manager, thirty-five to forty-five years of age; aggressive, executive type, qualified to command attention of large interests; experienced in ball bearing, automobile or tractor fields. Duties: In charge of younger sales engineers; will visit the trade when necessary, keeping in touch with field conditions. Salary commensurate with ability; name what desired.

V-496. Electrical engineer, thirty to thirty-five, in rapidly growing company in Detroit, manufacturing electrical devices, to take full charge of engineering department, including development, design and drafting, production engineering and tool designing. Must be aggressive and able to get results. Experience in modern manufacturing methods and technical training essential. Three to four thousand per year, depending upon qualifications. State experience, education and salary wanted.

V-497: Wanted—A competent research engineer in problems relating to radio telegraphy. Must be technical graduate from engineering college and have had considerable practical experience in radio engineering problems after graduation. Send credentials and resume of technical experience.

V-498. Wanted—Salesman to sell small electric motors in Middle West. Also a salesman to sell motor-generators.

V-499. Technical graduate with sales ability. Should have experience in operation of direct current motors and generators. Excellent opportunity for advancement. State experience and salary expected. Location, Cleveland, Ohio.

V-500. Graduate electrical engineer, one or two years construction experience to supervise installation of oxy-hydrogen electrolytic plants and train operators. Part time on road, all expenses paid. Salary to start $100.-$125. per month. Headquarters near New York.

V-501. Electrical engineer for installation and maintenance, large manufacturer in Ohio. A-1 man, 30 to 35 years of age. Salary between $3000. and $5000. In reply give complete record of experience and salary desired.

Junior Electrical Engineer (male), ($1080.-$1200.), Bureau of Mines, Dept of Interior, for duty at Pittsburgh, Pa., or elsewhere. The United States Civil Service Commission announces open competitive examinations for this position and positions requiring similar qualifications. Examination May 7, June 4, and July 9, 1919. Applicants should at once apply for Form 1312, stating title of examination desired, to Civil Service Commission, Washington, D. C.

SERVICES AVAILABLE

1203. Electrical Engineer. Technical graduate, twenty-seven years old, married, four years' experience in charge of experimental laboratory in technical college and with large electrical company, desires responsible position with company offering wide experience in electrical engineering. At present in charge of developing and testing electrical apparatus. Salary $3000.

1204. Electrical engineer, university graduate, at present electrical officer in U. S. N. R. F., available for technical executive position on reasonable notice. Six years broad technical experience. Proven ability in inventive and development work. Age 28. Associate A. I. E. E. Excellent references regarding ability, fitness and character.

1205. Mechanical and electrical engineer wishes engagement by American corporation in reconstruction work in France. Forty-three years of age, married, four years steamship engineer experience, seven years superintendent of hydroelectric plant. Wide all-round practical experience. Speak and correspond English, French and Spanish. Engaged at present, but available May 1.

1206. Electrical engineer, married, age twenty-eight years. Eight years' experience as cable engineer in large electric cable manufacturing plant. Thoroughly familiar with construction methods of manufacture, design and testing of rubber, varnished cambric and paper insulated power cables, also submarine telephone and telegraph cables.

1207. Electrical graduate, G. E. test and commercial experience desires position as office assistant in commercial or engineering office of manufacture. Honorably discharged from Army.

1208. Practical engineer who has had complete charge of a 4000 H. P. aviation motor manufacturing plant during the war, wishes to get back into construction work. Ten years experience. Familiar with labor conditions. Will go anywhere. Has erected modern electric power apparatus of all kinds. Present salary $3300. per year.

1209. Electrical engineer returning to England in May. Thirteen years experience with design, construction and operation of A-C. and D-C. power plants and distribution systems, expert draftsman; five years shop experience; accustomed to handling men; desires position as operating engineer or superintendent of construction. Married, age 35, salary $2000.

1210. Mechanical and electrical engineer, age 34. Experienced in directing design and construction of power, mining and metallurgical plants in the

Southwest and Mexico. Available April 1. Salary $300. per month.

1211. Electrical engineer, eight years practical experience in constructing, operating and designing central stations and substations, high-tension equipment, etc. Seven years teacher of electrical subjects. Capable of taking charge of design of high-tension hydroelectric or steam driven plants. Salary $3500.

1212. Returning from France a Captain of Engineers. Associate A. I. E. E., member A. I. M. E. Thirty-five years old, unmarried, technical education. Last six years of civil life as chief electrician, master mechanic and superindendent of construction with two medium size mining companies. Immediately available.

1213. Executive Engineer. Extensive experience in construction and operation of power plants, high-tension work and power applications. Desire position where executive ability and engineering experience are required. Foreign position considered. Minimum salary $6000. per year.

1214. Member A. I. E. E., 28 years old, graduate (1914) of electrical engineering course, desires position, preferably power or construction work. Three years in testing department of large central station company, six months experimental work in electric welding, thirteen months electrical work in Navy as lieutenant (junior grade). Working knowledge of French.

1215. Graduate electrical engineer, four years telephone, one year radio work, 27 years of age, single, desires opportunity in manufacturing, installation or construction work requiring executive ability and handling of men. Minimum salary $2000.

1216. Captain United States Army expects early separation from the service. Technical graduate in electrical engineering with several years' experience in operating and commercial work with Public Service light and power corporation. Two years military service as personnel officer supervising selection of men and organization of the Army. Position desired as employment supervisor or commercial and sales engineer.

1217. Technical graduate, four years experience in electrical contracting as field and office engineer; on industrial light and power installations, desires permanent position where changes of advancement are unlimited. Have thorough business as well as electrical experience. Salary $1600.

1218. Electrical engineer, 31, college graduate 1911, 1st Lieut. S. C., just discharged after fourteen months in France, desires position. Expert on power transmission line, substation and distribution system design, construction, operation and maintenance. Other valuable engineering and business experience. Conversant with public utility operating methods. Minimum salary $2400.

1219. Executive Engineer or Assistant Manager. Graduate electrical and mechanical engineer, age 30, experienced in power plant and substation construction, operation and maintenance; organization; appraisal engineering; steel mill operation and machine shop practice. Executive ability and can handle men. Recently released, Lieutenant, U. S. N. Position as executive engineer or assistant manager with opportunity for advancement. Salary $3600. to $4000. Eastern location preferred.

1220. Graduate in electrical engineering, correspondence school course. Eight years in charge electrical construction for engineering firm; two years operating in substation; two years power plant operation. Desires position where past experience may be of service.

1221. Electrical engineer, age 32, technical graduate with degrees B. S. and M. S. Post graduate at Massachusetts Institute of Technology. Finished Westinghouse apprenticeship, then had six years experience in operating, inspecting, station and substation design with large operating company. Desires position in Philadelphia.

1222. Graduate electrical engineer, age 30, married, two years testing department, one year engineering department, General Electric Company. Three years engineering department large power company on transmission, substation and power engineering. At present professor of electrical engineering in recognized technical school. Wish position in engineering department of power or electric railway company.

1223. Electrical, mechanical engineer, ten years experience in research, design and testing of mechanical and electrical devices and machines, also wireless telegraphy experience and power plant, wants a responsible position in engineering department laboratory of factory organization. Speaks four languages.

1224. An electrical engineer experienced in the management of public utilities wishes to correspond with a company requiring a manager.

1225. Army Captain. Technical graduate having had twelve years of varied engineering and executive experience, desires to connect with manufacturing concern, financial institution, or technical publication. Would be particularly valuable to a concern interested in making engineering studies and reports regarding physical conditions and values of properties.

1226. Technical graduate, seven years practical experience, desires position upon release from duty. At present assistant inspector (electrical) in office of the Inspector of Engineering Material, U. S. N. Familiar with manufacture of cable, electrical machinery, measuring instruments, wireless apparatus and electrical material in general. Familiar methods of production and routing of material. Age 26. Married. Good personality, highest references. Minimum salary $1800.

1227. Technical graduate. Electrical engineer. Eight months with central station company, meter work, laboratory research. One year with electrical manufacture testing, inspection, experimental work. Graduate signal corps school for radio engineering, Yale University. Desires position with opportunity for advancement.

1228. Graduate electrical engineer, recently discharged from Army, one years' experience testing, general manufacturing and office work withWestinghouse Elec. & Mfg. Co. One year as engineer with Westinghouse and the Signal Corps. Age 26.

1229. Erecting engineer, technical graduate, married, age 28, available July 1st. At present Major, A. G. D., U. S. A., in charge of demobilization of fifteen states. Over 7 years practical experience as consulting construction engineer. Thoroughly familiar with lay-outs, right-of-ways, appraisals and reports, knowledge of French, Bohemian, Russian. American born. Desires position abroad as erecting engineer in power plants and high tension transmission lines. Minimum salary $5000.

1230. Live Wire—Electrical engineer and lawyer wants permanent position as executive engineer, manager or purchasing agent large corporation. Now Captain U. S. Army supervising construction and operation $100,000,000 war plants. Nine years experience power house and electrical railroad, design, construction and operation. Important investigation, contracts, specifications, purchases.

1231. Officer about to be discharged, experienced in induction motor installation, operation, emergency repair and maintenance. Three years experience in large industrial plant in charge of above work at entry in military service. Technical graduate, degree, age 26, unmarried, can go anywhere.

1232. Member A. I. E. E., Member A. S. M. E., age 39. Fifteen years experience covering all branches of electrical and mechanical engineering for industrial and power plants, electrical distribution systems, tests, investigations and reports. At present employed as electrical engineer in War Department. Can be released shortly.

1233. Superintendent of Power or Chief Engineer, twelve years experience with most complicated operating conditions of street railway, lighting and power, high tension transmission and steam heating; specialized in economic combustion of coal and boiler-room problems. Available June 1.

1234. Electrical and mechanical engineer, graduate, seven and one-half years practical experience from Westinghouse apprentice to assistant master mechanic and engineer of equipment interurban electric railway (four and one-half years) manufacturing own rolling stock; one and one-half years foreman electrical construction; Army engineer one year. Associate A. I. E. E. Experienced in handling men. Age 31. Married. Desires position as electrical engineer or chief electrician. Salary $175.

1235. Graduate electrical engineer desires opportunity in teaching or with firm of engineers. Has completed post graduate university course of three years, taught three years as a member of the electrical engineering faculty of large American university, practical engineering five years. Especially qualified to direct research, technical investigations and pioneer engineering. Mar gations and pioneer engineering. Marked success in handling men.

1236. Hydroelectric engineer, college graduate, Member A. I. E. E., Associate Member A. S. C. E., 37 years old. Wide experience in design and construction of medium and high head plants, including hydraulic and electrical features and electrical application to mines. South American experience; reports, estimates and tests. Salary $4000. in U. S. A.

1237. Electrical engineer, technical graduate, single, has eight years of power generation, control, distribution and illuminating engineering experience, desires permanent connection. Possess initiative and executive abilities. Until recent date with War Department, Construction Division, Washington, D. C. Associate A. I. E. E. and I. E. S.

ACCESSIONS TO THE ENGINEERING SOCIETIES LIBRARY

(From February 1st to February 28, 1919)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

THE ELEMENTS OF WOODEN SHIP CONSTRUCTION.

By W. H. Curtis. 1st edition. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1919. 223 pp., 199 illus., 9 x 6 in., cloth, $2.50.

A revised and enlarged edition of a course prepared for the Education and training Section of the Emergency Fleet Corporation. It is intended for the use of carpenters and others who, though skilled in their work, lack the detailed knowledge of shipbuilding necessary for efficiency.

FIGHTING THE BOCHE UNDERGROUND.

By H. D. Trounce. N. Y., Charles Scribner's Sons, 1918. 234 pp., 7pl., 1 por., 1 diag., 8 x 5 in., ¼ cloth, $1.50. (Gift of author).

Captain Trounce, an American mining engineer, enlisted in the Royal Engineers in 1915, and transferred to the Engineer Reserve Corps of the American army in 1917. His book is a description of the underground fighting in which he participated in Flanders, at Arras, Vimy Ridge and elsewhere.

INDUSTRY AND HUMANITY.

A Study in the Principles Underlying Industrial Reconstruction. By W. L. Mackenzie King. Boston and N. Y., Houghton Mifflin Company, 1918. 567 pp., 10 charts, 8 x 6 in., cloth, $3.

This volume by the former Minister of Labor of Canada is a statement of the underlying principles which are finding expression in the organization of industrial society and which should obtain in all efforts at reconstruction. The book is based on the author's twenty years of personal contact with labor problems, supplemented by a study of the literature of the subject.

INSTINCTS IN INDUSTRY.

A Study of Working-Class Psychology. By Ordway Tead. Boston and N. Y., Houghton Mifflin Company, 1918. 222 pp., 8 x 5 in., cloth, $1.40.

With the idea of contributing to a better understanding of people in their capacity as manual workers, Mr. Tead has analyzed in turn the ten basic instincts on which our life and conduct rest, has shown how each affects the worker's relation to his job, and how each must be studied and used in the task of attaining sound relations between the employer and the employed.

THE INSTRUCTOR, THE MAN AND THE JOB.

A Hand Book for Instructors of Industrial and Vocational Subjects. By Charles R. Allen. Phila. and Lond., J. B. Lippincott Co., (copyright 1919). 373 pp., 8 x 5 in., cloth, $1.50.

The author, who has been Agent for Industrial Training for the Massachusetts Board of Education, and Superintendent of Instructor Training for the Emergency Fleet Corporation, gives the result of his experience in this volume, which is intended as a handbook for instructors in industrial plants and as instruction notes in training courses for instructors.

JOHNSON'S MATERIALS OF CONSTRUCTION.

Rewritten by M. O. Withey and James Aston. Edited by F. E. Turneaure. 5th edition. N. Y., John Wiley and Sons, Inc.; Lond., Chapman and Hall, Ltd., 1919. 840 pp., illus., 1 pl., 1 por., tab., 9 x 6 in., cloth, $6.

As the progress of the past twenty years in the knowledge of the properties of materials made Professor Johnson's book an inadequate account of the subject, it has been rewritten under the editorship of his successor at the University of Wisconsin.

The authors have aimed to retain the broad scope of the original work as a statement of the essential information concerning the sources, manufacture or fabrication of the principal materials, their more important mechanical and physical properties and the influences of various factors upon them, the causes of defects and variations, the methods of testing and their general uses.

The arrangement of the book is new and some changes have been made in its scope. Obsolete matter has been eliminated and modern data substituted. The volume is intended to serve both as a textbook and as a work of reference.

1919 RECORD OF AMERICAN AND FOREIGN SHIPPING, NEW YORK:

Published by the American Bureau of Shipping, "American Lloyds." N. Y., 1919. 1056 pp., 10 x 10 in., morocco.

The 1919 Record presents no change in form from previous years. It provides a record of American and foreign vessels, classified according to the rules of the Bureau, and is endorsed by the Navy Department and the boards of marine underwriters of New York, Boston and San Francisco.

In addition to the list of vessels, there are lists of owners, marine underwriters' representatives, surveyors, machinery constructors, dry docks, marine railways and ship builders. An index of changed names is also included.

OUR NATIONAL FORESTS:

A Short Popular Account of the Work of the United States Forest Service on the National Forests. By Richard H. Douai Boerker. N. Y., The Macmillan Company, 1919. 238 pp., 80 illus., 8 x 5 in., cloth, $2.50.

CONTENTS: The Creation and Organization of the National Forests; The Administration of the National Forests; The Protection of the National Forests; The Sale and Rental of National Forest Resources; Appendix:—Table of Land Areas within the National Forest Boundaries, June 30, 1917.

The author presents a well-illustrated account of our national forest problem and of the work of the Forest service. Written in popular form and based largely on his personal experience and observation.

PETROLEUM REFINING:

By Andrew Campbell, with a foreword by Sir Boverton Redwood. Lond. Charles Griffin and Co., Ltd., 1918. 277 pp., 138 illus., 29 folding pl., 3 diag., 11 tab., 9 x 6 in., cloth, $8.50.

This volume, the only book in English devoted soley to the subject, describes the ordinary methods used to prepare marketable products from petroleum, except "cracking" methods. The work is based on extended practical experience, is well supplied with illustrations and drawings and includes a bibliography.

PHYSICS FOR TECHNICAL STUDENTS. SOUND, LIGHT, ELECTRICITY AND MAGNETISM.

By William Ballantyne Anderson. 1st edition. N. Y., McGraw-Hill Book Company, Inc.; Lond., Hill Publishing Co., Ltd., 1919. 794 pp., 373 illus., 9 x 6 in., cloth, $3.

This book completes the author's textbook of physics. the first part of which has been published previously under the title: "Mechanics and Sound". The writer has aimed to produce a college text especially suitable for students of agriculture and engineering, in which particular attention is directed to practical applications of the subject.

PRACTICAL SHIP PRODUCTION:

By A. W. Carmichael. 1st edition. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1919. 52 pp., 101 illus., 9 x 6 in., cloth, $3.

The purpose of this book is to serve as an introduction to the subject by presenting the most important general principles of ship design and describing the various processes of shipbuilding. The treatment is practical rather than theoretical and matters of construction are more fully considered than problems of design.

THE RUDDER DIRECTORY:

A Trade List of Shipbuilding and Marine Industries. Compiled and issued by The Rudder Publishing Company. N. Y., 1919. 332 pp., 1 pl., 9 x 6 in., cloth, $5.

Included in this directory are lists of the steel, wood, composite and concrete shipyards, with the names of their officers, ship and engine repair plants, dry docks and marine railways, owners and operating companies, marine insurance companies, boat builders, engine builders, ship chandlers and manufacturers of equipment, parts, etc. A supplement, revised to Feb. 6, 1919, brings the data concerning the U. S. Shipping Board and the Emergency Fleet corporation up to date.

THOMAS' REGISTER OF AMERICAN MANUFACTURERS AND FIRST HANDS IN ALL LINES:

N. Y., Thomas Publishing Co., (copyright 1919) 4200 pp., 12 x 10 in., cloth, $15.

The tenth edition of this well-known trade directory is dated "October" as usual, although corrections were made up to December twentieth. The directory is divided into various lists, the chief one being a carefully classified list of manufacturers in all lines, subclassed geographically and provided with an extensive index to the classification. Other lists are of representative banks, boards of trade, chambers of commerce, etc., trade papers, leading trade names and an alphabetical list of manufacturers. The volume contains 4200 pages of information, conveniently arranged for quick consultation.

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*A complete list of the officers, committees and representatives of the Institute will be found in the January, 1919, issue of the Proceedings.

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*Inactive at present, due to the war.

PROCEEDINGS

OF THE

American Institute of Electrical Engineers

Vol. XXXVIII
Number 5

MAY, 1919

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TABLE OF CONTENTS

Section I.—Institute Affairs

Annual Meeting. Edison Medal Presentation 163
A. I. E. E. Annual Convention, June 24-27, 1919 163
Future Section Meetings 164
The New York A. I. E. E. Meeting, April 11, 1919 164
A. I. E. E. Directors' Meeting, New York, April 11, 1919 164
May Meeting of Radio Engineers 165
Reunion of Eighty-Niners 165
Engineering Council Announcement by National Service Committee 166
Classification and Compensation of Railroad Engineers 168
Smith-Howard Bill 170
The Engineer as a Citizen 173
Power Resources of North Atlantic States 174
Principles Underlying Radio Communication 174
Past Section Meetings 174
Past Branch Meetings 176
Associates Elected April 11, 1919 178
Associates Reelected April 11, 1919 186
Members Elected April 11, 1919 186
Transferred to the Grade of Member April 11, 1919 186
Transferred to the Grade of Fellow April 11, 1919 186
Recommended for Transfer 186
Applications for Election 187
Students Enrolled April 11, 1919 190
Personal 192
Obituary 192
Addresses Wanted 193
Engineering Service Bulletin 194
Accessions to the Engineering Societies Library 198

Section II.—Papers and Reports

Utilizing the Time Characteristics of Alternating Current. By Henry E. Warren, Boston, Mass., May 7, 1919 629

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GEORGE R. METCALFE, Editor.

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American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXVIII MAY, 1919 Number 5

ANNUAL MEETING, EDISON MEDAL PRESENTATION MAY 16, 1919

The annual business meeting of the A. I. E. E. will be held in the auditorium of the Engineering Societies Building, on Friday, May 16, 1919, at 8:30 p. m. The Board of Directors will present its annual report for the fiscal year ending April 30, 1919. This report contains a detailed statement of the finances of the Institute and a summary of the work of the various committees during the year.

The Committee of Tellers will present its report on the election of officers for the coming administrative year.

Announcement will be made regarding the Weaver Memorial Tablet which is to be erected in the headquarters of the Institute in acknowledgment of the services rendered to the Institute and to the electrical engineering profession by William D. Weaver. The tablet will be exhibited at this meeting.

Edison Medal Presentation

The presentation of the Edison Medal will follow immediately after the business of the annual meeting. The Ninth Edison Medal has been awarded to Benjamin G. Lamme by the Edison Medal Committee of the Institute "for invention and development of electrical machinery." In the absence of President Adams, Vice-President William B. Jackson will preside at the meeting. The program will be as follows:

1. The Edison Medal, by Carl Hering, Chairman, Edison Medal Committee.
2. Achievements of Benjamin G. Lamme, by B. A. Behrend.
3. Presentation of the Medal, by William B. Jackson.
4. Response, by Benjamin G. Lamme.

Ladies are cordially invited to attend this meeting.

A. I. E. E. ANNUAL CONVENTION JUNE 24-27, 1919.

As previously announced, the Annual Convention of the Institute will be held at the Lake Placid Club, Adirondacks, New York, June 24th to 27th, 1919.

The Convention Committee in conjunction with the Meetings and Papers Committee has practically completed the program for the Convention, the principal features of which may be announced as follows:

Tuesday Morning, June 24

1. President's Address, by C. A. Adams.
2. *Present Day Practise of Transmission and Tie Line Relay Protection*, by H. R. Woodrow, D. W. Roper, O. C. Traver, and P. Mac Gahan.
3. *Grounded Neutral*, (a) by H. R. Woodrow, (b) Wm. E. Richards.

Tuesday Evening

Informal Reception and Dance.

Wednesday Morning, June 25

4. Reports of Technical Committees.

Wednesday Noon

Conference of Committee on Development, Section Delegates and A. I. E. E. Officers, at luncheon.

Thursday Morning, June 26

Conference under auspices of Committee on Development, including Section Delegates and Institute Officers, open to all Institute members.

Friday Morning, June 27

5. *High-Tension Single Conductor Cables for Polyphase Systems*, by W. F. Clark and G. B. Shanklin.
6. *Electrostatic Field in Electric Power Cables*, by H. W. Fisher and R. W. Atkinson.
7. *Commercial Problems of 220-Kv. Power Transmission*, by A. E. Silver.
8. *The Effect of Transient Voltages on Dielectrics—II*, by F. W. Peek, Jr.

The committees have purposely left considerable time at the convention unassigned as it is expected that the conferences under the auspices of the Committee on Development will be one of the most important features of this convention and will undoubtedly occupy considerably more time than the sessions that have been scheduled. It is also the aim of the committees to leave plenty of time for social and recreation features including outdoor sports to which the location at Lake Placid is especially adapted.

A more complete program will be published in the June PROCEEDINGS.

FUTURE SECTION MEETINGS

Erie.—May 13, 1919, Erie Board of Commerce Rooms, 8 p. m. Subject: "Electro-Acoustic Shock Signalling." Speaker: Professor Vladimir Karapetoff. Lecture will be illustrated with working models, and lantern slides.

Rochester.—May 23, 1919. Subject: "Commercial Applications of Aluminum." Speaker: Mr. E. Blough.

THE NEW YORK A. I. E. E. MEETING APRIL 11, 1919

The 349th meeting of the Institute which was a joint meeting with the Illuminating Engineering Society was held in the auditorium of the Engineering Societies Building, Friday evening, April 11, 1919.

The meeting was called to order by Mr. George A. Hoadley, President of the Illuminating Engineering Society, who, after a few introductory remarks presented President Comfort A. Adams of the American Institute of Electrical Engineers.

President Adams briefly referred to the importance of the subject under consideration and introduced Mr. George H. Stickney, who read his paper on "Present Status of Industrial Lighting Codes."

The paper was discussed by Prof. C. E. Clewell, Chairman of the Lighting and Illumination Committee of the A. I. E. E., Dr. E. B. Rosa of the Bureau of Standards, C. B. Auel, of the Westinghouse Company, Dr. M. G. Lloyd of the Bureau of Standards, Ward Harrison; John Vogt, New York State Labor Department, W. P. Hurley of the Westinghouse Company, W. T. Blackwell, E. G. Perrot and Norman Macbeth. There were also communicated discussions by T. F. Foltz, Mechanical Engineer of the Pennsylvania Department of Labor and Industry, James R. Cravath, Electrical and Illuminating Engineer of Chicago, John A. Hoeveler and Dr. Louis Bell. After closure by Mr. Stickney the meeting adjourned.

A. I. E. E. DIRECTORS' MEETING NEW YORK, APRIL 11, 1919

The regular monthly meeting of the Board of Directors was held at Institute headquarters, New York, on Friday, April 11, 1919, at 2:30 p. m.

There were present: President C. A. Adams, Cambridge, Mass.; Past Presidents H. W. Buck, New York, E. W. Rice, Jr., Schenectady, N. Y.; Vice-Presidents John B. Taylor, Schenectady, Harold Pender, Philadelphia; Managers N. A. Carle, Newark, N. J., Charles S. Ruffner, St. Louis, Charles Robbins and Wilfred Sykes, Pittsburgh,

E. H. Martindale, Cleveland, Wm. A. Del Mar and W. I. Slichter, New York; Treasurer George A. Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

The following appointments by President Adams were announced: Dr. Frank B. Jewett and Dr. W. R. Whitney A. I. E. E. representatives on the Engineering Division of the National Research Council; Mr. W. L. Merrill, A. I. E. E. representative on the American Bureau of Welding.

The action of the Finance Committee in approving monthly bills amounting to $10,251.81, was ratified.

A Pacific Coast Convention was authorized, to be held in Los Angeles in September 1919, under the auspices of the Los Angeles Section.

In accordance with the recommendation of the Board of Examiners, the following action was taken upon pending applications: 113 Students were ordered enrolled; 236 applicants to the grade of Associate; 7 applicants were re-elected to the grade of Associate; 7 applicants were elected to the grade of Member; 5 applicants were transferred to the grade of Member; 1 applicant was transferred to the grade of Fellow.

The organization of Student Branches at Drexel Institute, Philadelphia, and the University of Pennsylvania, Philadelphia, was authorized.

A communication was presented from the Engineering Institute of Canada, to the effect that a committee of that Institute had been appointed to confer with the A. I. E. E. with the object of fostering the already cordial relations existing between the two organizations. The Board of Directors reciprocated by appointing a similar committee on cooperation with the Engineering Institute of Canada, consisting of Messrs. H. W. Buck, Chairman, W. A. Del Mar, and W. I. Slichter.

In addition to the above, many other matters relating to important activities and the general policy of the Institute were discussed and in most cases were referred to various committees and officers for further consideration.

Reference to these matters may be found in this and future issues of the PROCEEDINGS under suitable headings.

MAY MEETING OF RADIO ENGINEERS

The next meeting of The Institute of Radio Engineers will be held on Wednesday Evening, May 7th, 8:15 p. m., in Room 2, on the Fifth Floor of the Engineering Societies Building, 29 West 39th Street, New York.

A paper on "The Detecting Efficiency of the Thermionic Detector" will be presented by Dr. H. J. van der Bijl of the Western Electric Company. This paper describes convenient methods for measuring absolutely, or by comparison, the true detecting efficiency of vacuum tubes.

Members of the A. I. E. E. are cordially invited to attend.

REUNION OF "EIGHTY-NINERS"

Thirty years ago a party of American engineers belonging to the four National Engineering Societies, sailed for Europe with members of their families, visiting England and the Paris Exposition of 1889, and being the recipients of many high courtesies, official, professional, and individual.

Plans have been made for a reunion dinner, to be held in New York City about May 27th, at which it is hoped that all the survivors, ladies as well as men, of that memorable trip may meet again. While the records of the various societies furnish an approximately complete list of the party, it is possible that some have been overlooked, or that addresses may require correction.

It is therefore urgently requested that anyone who was of that party communicate immediately with Mr. Jesse M. Smith, Secretary of the Committee, at the Engineers' Club, 32 West 40th St., New York, N. Y.

This information is desired from every

member of the party, whether attendance at the function is possible or not; those who cannot come will be heartily remembered when their letters are read.

It is hoped that the response to this request will be immediate and complete; the time is brief and the information important.

Announcement of the precise date and place, and full details, will be sent to every individual who can be reached; send in your name now, and resolve to come to meet your travelling companions of thirty years ago!

ENGINEERING COUNCIL

Announcements by National Service Committee

TOPOGRAPHIC MAPPING

Engineering Council through its National Service Committee, is advocating the rapid completion of a topographic map of the United States, and in furtherance of this object has addressed a letter to the Secretary of the Interior urging an increase in the next Federal appropriation for the Geological Survey. The following is an abstract of the communication to Secretary Lane:

It has become apparent to engineers and others engaged in development work that the Geological Survey should be granted a more liberal appropriation for topographic mapping.

It would require much space to review the needs for and the uses of a complete topographic map. We mention merely a few. It is obvious that the maps are essential as a basis for National defense, and hardly second in importance is their need in connection with the enormous road building program upon which the government has entered. The Federal policy of arid-land and swamp-land reclamation is also responsible for increased map necessities, and not less important is the matter of power supply. The Boston-Washington power survey is merely one of many examples where a complete topographical map becomes a fundamental necessity. In the fields of mining and geology and in the development and extension of railway systems, the topographic map has also become a necessity.

There are trained topographers available to accomplish topographic work during the next fiscal year equivalent to the expenditure of **$1,000,000**. It is believed that the several states can be induced to make appropriations aggregating **$500,000** for the next fiscal year. This would leave the sum of **$500,000** to be appropriated by Congress. It seems to us reasonable and wise to advocate such an appropriation for the next fiscal year.

If you find it possible to recommend to the 66th Congress an appropriation of $500,000 for the above recommended work in the next fiscal year, you will have the support of practically all American engineers and others who are well informed as to the necessities.

THE SIXTY-FIFTH CONGRESS

Engineers have reason for sorrow over the engineering legislation that died in the Sixty-Fifth Congress merely because there was no opportunity for a vote. The bills in which engineers are most concerned usually fail to become laws, not because of adverse votes on the merits, but because of no votes.

Legislative measures do not succeed in Congress merely by reason of merit. Congress is deluged with bills. Under such conditions the legislation must be the result of interested work by persistent advocates. Engineering legislation usually fails because there are no engineers in Congress to become its champions.

The big engineering measures, with one exception, arrived at the point of final vote at the 11th hour, were caught in the jam of filibuster, and died. There was one engineering measure that passed, namely, the appropriation for public highways, but this was a rider on the Post Office appropriation bill.

GOOD ROADS LEGISLATION

The Government is embarked on a road making policy which is the biggest and most costly internal improvement program ever known in our history. The Federal Road Act, approved July 11, 1916, provides for an appropriation as follows:

Year ending	June	30th,	1917	......	$5,000,000
"	"	"	"	1918	10,000,000
"	"	"	"	1919	15,000,000
"	"	"	"	1920	20,000,000
"	"	"	"	1921	25,000,000
Total				....	$75,000,000

This sum is to be expended for the construction and improvement of highways under the direction of the Secretary of Agriculture. Each state receiving benefits must secure approval of the Secretary of Agriculture to the road projects that it is desired to build, and the Federal appropriation is then made available for construction in an amount not exceeding 50 per cent of the total cost. The state must appropriate and use an amount of money equivalent to that made available from the Federal treasury, so that there became available for road building purposes the sum of $150,000,000 from Federal and state sources during the five years ending June 30th, 1921. This is not all.

The Post Office appropriation bill passed by the last Congress increased the statutory limit of unit cost of highways built under its provisions from $10,000 to $20,000 per mile and appropriated in addition to the sums above mentioned a further sum of $50,000,000 for the fiscal year ending June 30th, 1919, and $75,000,000 for each of the two following years. Thus we have a total of Federal and State moneys available to June 30th, 1921 of $550,000,000, to which may be added an additional $10,000,000 appropriated by Congress for roads and trails in the National Forest.

The problem of transportation in all its manifold aspects must be considered by the next Congress. It is estimated that about 90 per cent of our internal commerce is hauled over the highways of the country. Therefore the Federal highway policy must come up for review as an important factor in transportation. As it is essentially an engineering problem, great burdens will fall upon engineers if the correct solution is to be reached.

MINERAL LANDS BILL

The mineral resources of the public lands of the United States are, except the precious metals, locked away from development. For more than eight years there has been an attempt by both the Executive and Legislative departments of the nation to secure legislation which, under proper conditions and without detriment to the public interest, will open up these lands for development. Suffice it to state that after eight years of study, argument, conciliation, and compromise Congress agreed in conference of the two Houses upon a measure satisfactory to it and to the Executive Department. The final draft was passed by the House of Representatives, but in the Senate it was talked to death by Senator LaFollette of Wisconsin. The intention is to reintroduce the bill into the 66th Congress, where it is hoped it will be regarded in the nature of unfinished business and thus receive early consideration and passage.

THE WATER POWER BILL

The fate of this bill was the same as that of the mineral lands bill above described. This subject has been before Congress for ten years and is without question one of the most important economic matters on the Congressional calendar. The trouble with present water power laws is that they do not confer on developers of water power any title which can be used as a basis of credit. This condition had brought water power development to a virtual standstill in all situations in which the Federal Government has jurisdiction. The difficulties have at last been adjusted, and the bill agreed to in conference and adopted by the House is what engineers would call a pretty good measure.

It is the intention to introduce this bill at an early date in the 66th Congress, and if it can be considered as unfinished business, there is no reason why there should not be speedy passage.

Engineering Council Announces a National Legislative and Departmental Information Service for Engineers in all Branches of the Profession

This service has been placed under engineering direction, so that responses to inquiries will be specific and suitable for engineering use. Engineering Council has established this service in response to frequent expressions of need. Its continuance will depend largely on its use by the engineers of the country. No charge will be made for such services as the committee can render.

The Statistical, Research and Construction bureaus of the Government have become valuable sources of engineering information, but have not been used by engineers to the extent merited by the character of their material. Many matters before Congress involve engineering considerations, of which members of the Profession should be aware.

Set forth in specific language the kind of information wanted.

Address the National Service Committee, M. O. Leighton, Chairman, 502 McLachlen Building, Washington, D. C.

CLASSIFICATION AND COMPENSATION OF RAILROAD ENGINEERS

This subject held the attention of the Railroad Administration's Board on Wages and Working Conditions for three days, during which time it heard representatives of Engineering Council and the American Association of Engineers. Prior to meeting the Railroad Administration's Board, Engineering Council had studied the subject through its Committee on Classification and Compensation of Engineers. Representatives of Council and the Association also planned a program based on the results of a meeting of railroad engineers on March 17, 1919, called by the American Association of Engineers for the purpose of getting exact data and tentative instructions.

Mr. Stuart opened the hearing for the Council by reviewing existing conditions, explaining the field covered by those organizations and introducing the representatives of the American Association of Engineers. Brief of his statements follow:

The Engineering Council through this Committee desires to express to your Board its belief that it is to the best interest both for the social and economic welfare of the Railroad Professional Engineers of the United States that the case of these younger engineers or engineers holding these subordinate positions be further considered.

Before the war the compensation of the engineers was notably inadequate and the increases which have been granted the men in the subordinate positions do not seem to them sufficient. Engineering Council, through its Committee, asks that employees of the Engineering Departments, civil, mechanical, electrical and signal, who were not considered in the Officer or Supervisory force but who will, from their technical education or training at some later date occupy the higher positions in these departments, be given a classification and the titles of these positions standardized, and a proper remuneration be given them in order that their physical welfare and mental interest may be provided for so as to insure efficient service to the public.

The members of the founder societies of Engineering Council have occupied these identical positions in their day and hence speak to you from experience, but we recognize that Engineering Council has not the direct touch with these younger engineers employed by the railroads of the country, to handle the details of the matter in the way you may desire and we are therefore further requesting that your Board have the necessary data collected and considered so that it may be certain that this particular class of employe has been treated with justice comparable with other classes of employes who have been given separate classification in the railroad service.

Associated with Engineering Council in this hearing is the American Association of Engineers, a National engineering organization which includes in its membership a large proportion of the younger engineers in railway service who occupy subordinate positions. The American Association of Engineers has held a conference of railway engineers to consider wage matters, and comes before you with the direct support of the larger proportion of railway engineers in the country.

Representatives of this organization are present and we urge that you give their views due consideration. Engineering Council is anxious and willing to give you any advice or assistance they can in the matter.

Mr. Drayer, Secretary of the American Association of Engineers, gave an account of the origin and character of his association. He then presented a wage schedule for subordinate engineers as it had been approved by the Railroad Engineers' Convention in Chicago on March 17, 1919. His explanation was followed by a detailed account of the preparation required for a railroad engineer. Mr. W. C. Bolin, Chief of the Sub-Committee on Railway Wages, covered this subject and estimated that the education required to fill an average railway engineer's place represented a capital of $10,000.00. At the present scale of wages, he declared it impossible for the engineer, except under unusual circumstances, to recover his $10,000.00 investment in education. The apprentice in the mechanical department, he told the Board, is better off than the boy who enters school to take an engineering course. The apprentice earns money while the other boy is spending money for education, and under the existing rate scale, the former would continue to get more money throughout his career.

It was further shown that on some railroads, the tape men in the engineering organization get as little as $55.00 per month and the work is exceedingly responsible—tape measurements must be exact. A case was cited in which a bridge was thrown out of line six feet because an engineering party was obliged to use an inferior tape man.

To substantiate this evidence and to emphasize the need of increased compensation, Mr. Beahan cited the result of his long experience in railroad work. He explained the education required preparatory to various railroad positions. Up to quite recently, men would put in their summer vacations to get practical experience in railroad work and would then go with the company at comparatively small pay at the time they graduated. Under existing rates of pay, there is no inducement for a college man to enter this service and the old railway engineering recruiting plan will fail if present rates are maintained. The result is that good men will not be available for the higher positions in railroad work. It is Mr. Beahan's opinion that labor unions are not appropriate organizations for engineers to bond themselves together under—first, because engineers' work is not such that it requires extended organization; second, that any such organization would invariably create trouble. Statistics brought out the fact that the cost of living for railroad engineers had increased at least 50 per cent, whereas the average increase in compensation for this same class of employes had been only 35 per cent. Mr. Beahan's experience taught him that it was best to pay men in this kind of work all you can afford and continually hold an incentative for advancement before them. The classification of railroad engineers has gotten into the rut and muddle that now exists, because they were all directly under the Chief Engineer who generally had to give final approval to recommendations for raises in pay or change in classification.

Five railway engineers from the various fields of railroad work were then called before the Board to testify as to the relative value of various positions coming under them. The field of the junior civil engineer, the electrical engineer and the inspector was covered with the intention of drawing parallel lines through the various positions so that definite classification could be recommended. The testimony showed that there was a good chance for this classification under existing conditions and this will probably be one of the first steps in arranging for increased compensation.

The full Board was present at the hearing and manifested unusual interest in the entire proceedings. They took extensive notes, asked pertinent and important questions and indicated that they realized the importance of the subject and was well disposed toward the contentions made by the Council and American Association as representatives of the railroad engineers.

Following this hearing, it is contemplated that substantial increases in salaries for the junior technical engineers on railroad work is in sight and will very probably be a reality as soon as the Board can get additional data and information required to complete its work.

SMITH-HOWARD BILL

Engineering Experiment Station Legislation

Statement by Author

To the Editor, A. I. E. E. Proceedings:

The wording of a statement in the February PROCEEDINGS page 130, Sec. II, and that of another statement in the April PROCEEDINGS, page 137, Sec. I, has caused some misunderstanding relative to the Smith-Howard bill proposing the establishing of Engineering Experiment Stations in each State and Territory to perform work in Engineering and Industrial Research for the benefit of American industry and commerce, corresponding to the work of the Agricultural Experiment Stations in the interest of American agriculture.

One statement makes it appear that the author has endorsed another and radically different form of legislation, and the other also unintentionally gives the impression that those supporting this legislation are far from united. This statement is intended to correct these erroneous impressions if by chance they have been formed in the minds of the readers of the PROCEEDINGS as is known to be the case in several instances.

Dr. Richard C. Maclaurin, Chairman of the National Committee on Engineering Experiment Station Legislation called a meeting of this Committee in Washington, Dec. 9, 1918. A motion was carried establishing as the sense of that meeting two fundamental principles as expressed by Dr. Maclaurin and put into a motion by Dr. K. G. Matheson: first, the principle of federal support in equal amounts to each State, as proposed by the Smith-Howard bill for the promotion of engineering and industrial research; second—the principle of distributing that support to institutions, not to individuals.

Later in the discussion, which was very pronounced, favoring the establishing of Engineering Experiment stations, the writer made the motion which was carried unanimously that "The Chairman, Dr. Maclaurin, be authorized to appoint a committee on the bill for the purpose of receiving written statements from organizations and individuals as to the improvement or modification of the bill which had been accepted by Dr. W. M. Riggs, President of the Land Grant College Engineering Association and his Executive Committee as the instrument of procedure for the National Committee."

Eight national organizations were invited to send delegates to a meeting of the National Committee in Washington Jan. 6, 1919, and submit their opinions or recommendations officially. These included the Engineering Council and the National Research Council. The Engineering Council requested its Washington representative to attend the meeting and report on the discussion but without power to act. It should be remembered that this meeting was for the purpose of receiving in writing recommendations for modifications of the Smith-Howard bill and to hear the discussion on the same. Since many prominent national organizations were represented it was natural that a considerable variety of opinions was expressed.

The National Committee and all the

Land Grant Colleges were unanimously in accord with the principle of establishing the Engineering Experiment Stations in each State and Territory for the promotion of engineering and industrial research which will substantially fulfill the long needed completion of the Land Grant College System. This most wisely conceived and developed system incorporates two fundamental divisions—1. Agriculture, 2. Engineering, (called "Mechanic Arts" in the Act of Congress; 862 providing for the establishment of the so-called Land Grant Colleges).

In agriculture, Congress now provides for three important activities, *i. e.*, 1. Education in Agricultural Arts, 2. Agricultural Research in the Agricultural Experiment Stations provided for by Congress. (H. R. 345. approved March 16, 1906) and established by the State Legislature of each State in connection with that institution or institutions, (either the Land Grant College or a separate institution) which in its judgment would best serve the purposes of that Act. 3. Extension, or the systematic distribution of such available agricultural information as will promote the most efficient, economical and productive methods in American agriculture.

With such a system it was easy and very profitable for the United States to feed itself and a very large part of the world with comparatively little disturbance during five years of a world war that was more terrible and widespread than any one thought possible. Bright as it is, the record of our war achievements would have been vastly more creditable to America and hundreds of millions of dollars would not have been wasted in the necessarily hurried and frantic engineering, industrial, military and naval research and, of most importance, hundreds if not thousands of lives might have been saved had the needed Engineering Experiment Stations been established by Congress ten years or more ago instead of waiting for the stern lesson of this war to impress the need, wisdom and justice of such preparedness. Our salvation is credited largely to the already established Research Bureaus of the several Departments of the Administration, aided by civilian and privately supported organizations.

In engineering, Congress now provides in the Land Grant Colleges, only for Education in the "Mechanic Arts." To complete the system, the activities of Engineering and Industrial Research and Extension are now provided for in the Smith-Howard Bill, to properly and necessarily correspond to similar activities in the various fields of Agriculture in its broadest interpretation.

The Engineering Council, the Engineering Foundation and the National Research Council were extended special invitations by the writer, the author of the Smith-Howard bill, to give their support, in some proper way to this legislation which is non-partisan politically, professionally or educationally. On December 4, 1918, prior to the above mentioned meetings, a special committee of the National Research Council met in Washington to consider this bill and by invitation the writer attended this meeting and took part in the discussion.

This committee unanimously recommended to the National Research Council the principle of equal federal grants to each State and Territory for the support of scientific and industrial research. It was further recommended for the consideration of the Council, though not unanimously approved by individual members of the committee, that the funds appropriated by Congress be allocated to various institutions and individuals from year to year by state boards under the supervision of a federal agency, (such as the National Research Council).

When called upon to discuss the propositions before the committee, including that to do away with the system of Engineering Experiment Stations as provided in the Smith-Howard bill and endorsed by the Land Grant Colleges, the writer earnestly reiterated his conviction that the well defined objects and results as proposed by the Smith-Howard bill could best be secured by means of a permanent and thoroughly responsible system of State Engineering Experiment Stations directly related to the Department of Commerce, one of the executive branches of the United States Government, in which is the United States Bureau of Standards engaged in doing for the federal government substantially what is proposed that each Engineering Experiment Station shall do for its respective State.

The writer appreciates the excellent work that has been done by the National Research Council in the three formative years of its existence. The provisions of the Smith-Howard bill are such as to warrant the earnest support of the Council under its purposes and duties. In the last mentioned Washington meeting of the committee of the Council the writer expressed his earnest desire to see the work of the Council in some way related to this system of State Engineering Experiment Stations and made well defined suggestions as to how such a relation might be established which would meet with the approval of the large majority of colleges and individuals who were giving their support to this legislation in Congress.

On the same day the writer was requested to serve on a committee with four members of the Council to draft a revised form of the Smith-Howard bill incorporating the principle of state boards, for the purpose of submitting these suggestions to those supporting the bill and the system of Engineering Experiment Stations. While serving on this committee and making suggestions relative to the wording of some of the provisions of the proposed revision it was well understood by the Committee and the Council that the writer did not sponsor these radical changes but was glad to convey the statement of them to the friends of the Smith-Howard bill for consideration.

Later a member of the Council expressed the opinion that Congress would require that, as in former and similar legislation, the proposed system of Engineering Experiment Stations be related definitely with the proper administrative department of the government, such as the Department of Commerce. This principle is now universally accepted by the National Committee, including members of the Council and the Land Grant Colleges.

At the annual meeting of the Land Grant College Engineering Association January 8th, 1919, in Baltimore, attended by the representatives of nearly every Land Grant College, the proposed substitutes and compromises were rejected and the meeting declared unanimously in favor of the principle of completing the Land Grant College System by the establishing with federal aid and by Act of Congress an Engineering Experiment Station in each State and Territory with such provisions as to insure the establishment of the Station at that Land Grant College or constituent college of the Land Grant Institution established or which may be established by the Legislature in any state, which is best organized and equipped to carry on the proposed engineering and industrial research.

The revised form of the Smith-Howard bill prepared by the committee of the Land Grant College Engineering Association does not differ fundamentally from the form advocated by the National Committee. The difference of opinion relative to the method of legislative appointment is the principal and only real question to be decided by the Congressional Committee in charge of the bill. The National Committee will cooperate with the Land Grant College Engineering Association and other engineering scientific, industrial and commercial organizations and individuals in the effort to secure the early consideration of this long needed legislation in the interest of American industry and commerce. It is hoped and expected that the Engineering Council, the National Research Council and the individual National Engineering and Scientific bodies will lend their friendly influence to this specific legislation with the assurance that the several State Engineering Experiment Stations, and the great engineering schools and universities with which these stations may be connected and finally the Land Grant College Engineering Association will be found ready, at all times, to cooperate in promoting the highest interests of research, engineering and industry, the training of the young Americans for such activities and in supporting progressive federal and state legislation toward these aims.

The encouragement of American industry and commerce by means of the proposed system of Engineering Experiment Stations is highly endorsed by Secretary of Commerce Redfield and Dr. S. W. Stratton, Director of the U. S. Bureau of Standards and a member of the National Research Council by Dr. P. P. Claxton, commissioner of Education and other administration officials. Those interested in this bill are referred to the paper of Dr. W. R. Whitney, also a member of the Council, which will be found on page 115 of the February, 1919, PROCEEDINGS of the A. I. E. E., a masterpiece on American Engineering Research, and also the paper following by Dr. R. A. Millikan an able plea for research but which contains in its unrevised form the unintentionally misleading statement relative to the Smith-Howard bill.

PHINEHAS V. STEPHENS.
April 23, 1919.

THE ENGINEER AS A CITIZEN

On March 26th a symposium on the above subject was held in the Engineering Societies Building, under the auspices of the local sections of the American Institute of Mining and Metallurgical Engineers, the American Society of Mechanical Engineers and the Society of Automotive Engineers. Invitations to participate in the meeting were extended to fifteen other engineering societies, including the A. I. E. E.

Gano Dunn presided and addresses were given by Philip N. Moore, Calvert Townley, Nelson P. Lewis, Spencer Miller and C. A. Adams.

Philip N. Moore, past president of the A. I. M. E. spoke on the "Civic Responsibility of the Engineer, and pointed out that heretofore the engineer has been politically impotent because he has not made any effort towards civic activities and his reward in public esteem is proportional to his efforts. Since the war he has awakened to a new sense of responsibility as there has never been a time when the clear reasoning and exact knowledge of the engineer been more in demand.

Calvert Townley, past vice-president of the A. I. E. E. spoke on "The Relation of the Engineer to Legislation" and reviewed some of the ways engineers had attempted to influence legislation. He considered that any such attempt to be effective, should be concentrated on certain subjects which the public recognizes engineers as qualified to speak upon with authority.

Nelson P. Lewis, vice-president of the A. S. C. E. discussed the "Relation of the Engineer to Administration," stating that the engineer has formerly been excluded almost completely from the administrative business of the city and state by executives who felt that they could buy all the technical advice they needed at the prevailing rate. Lately there has been a growing appreciation of the importance of Engineering advice in public business. It is noteworthy that out of 88 cities that have adopted the City Manager plan 50 cities have selected professional engineers as chief executives.

Spencer Miller, vice-president of the A. S. M. E. spoke on the "Relation of the Engineer to Public Opinion" and pointed out that the engineer is assuming an ever larger position in public life and he should therefore make every possible effort to mould public opinion in the right direction. The speaker advocated the adoption of a thoroughly considered code of ethics to become the moral platform for all engineers.

C. A. Adams, president of the A. I. E. E. discussed the "Relation of the Engineer to Production and Distribution" which he stated was so much the normal work of the engineer that it would seem disconnected from his responsibilities as a citizen. One of the most important faults of our present methods is our terrifically expensive system of competition. Cooperation offers a means of elimination of wastefulness to an almost unbelievable extent and is a step towards the solution of the great problems that face the world.

A lengthy discussion followed the addresses, most of which centered on the organization of engineering societies. A resolution was passed urging the organization of a New York local engineering society. Resolutions were also passed requesting all engineering societies to appoint "committees on development" and also to appoint a joint conference committee to formulate a standard code of ethics.

POWER RESOURCES OF NORTH ATLANTIC STATES

At a technical session of the Institute held in Boston on the morning of March 14, a resolution was adopted endorsing the proposed investigation of the power resources and requirements of the north Atlantic coast region which is advocated by Secretary Lane, and suggesting to the Board of Directors of the Institute that the facilities of the Institute be offered to Secretary Lane in support of the project.

In accordance with this action and with the approval of the Board of Directors, the following resolution was transmitted to Secretary Lane:

> **RESOLVED, that the American Institute of Electrical Engineers hereby heartily endorses the proposed investigation of the power resources and requirements of the north Atlantic coast region, and hereby offers to Honorable Franklin K. Lane, Secretary of the Interior, who is advocating this investigation, the facilities and hearty cooperation of the Institute in support of the project.**

In acknowledging receipt of this resolution under date of April 3, Secretary Lane said: "I greatly appreciate the interest which the Institute has shown in this project, and its support, both in obtaining the necessary authority from Congress for the investigation and in prosecuting the investigation thereafter, will be most helpful. I propose to present the matter again at the new session of Congress and trust that the investigation may be authorized at that time."

PRINCIPLES UNDERLYING RADIO COMMUNICATION

The above is the title of a text book which has been prepared by the Bureau of Standards under the direction of the Office of the Chief Signal Officer of the U. S. Army, Training Section. The book contains about 350 pages, and starting with the elementary principles of electricity takes the student through a complete course on radio communication. The book has been designed for students with very little mathematical preparation and presents the subject with the use of only the most elementary mathematics. References to standard works are given for further study. Address, Supt. of Documents, Government Printing Office, Washington D. C.

PAST SECTION MEETINGS

Baltimore.—March 14, 1919, Engineers Club. Illustrated address by Mr. R. H. McLain on "Terminal Facilities." Attendance 60.

Boston.—April 9, 1919, Engineers Club. Subject: "Power Factor Correction." Speakers: H. R. Summerhayes, D. C. Jones and A. W. Copley. Attendance 85.

Chicago.—March 24, 1919, Western Society of Engineers Rooms. Address by Mr. A. H. Young on "Industrial Personnel Relations." Attendance 300.

Cleveland.—March 17, 1919, Electrical League Rooms. Paper: "Electrolysis in Underground Construction" by W. W. Walsh. Joint meeting with Assoc. of Iron and Steel Electrical Engineers. Attendance 96.

Denver.—March 15, 1919, Denver Athletic Club. Paper: "Building Lighting" by W. H. Bullock. Attendance 30.

April 9, 1919, Denver Athletic Club. Illustrated lecture by Lieut. Colonel H. S. Crocker on "Construction of Army Supply Base at Brooklyn, New York." Joint meeting with local association of A. S. C. E. Attendance 85.

Detroit-Ann Arbor.—March 21, 1919, Ann Arbor, University of Michigan. Illustrated lecture by Dr. Saul Dushman on "Modern Applications of the Electron Theory." Attendance 300.

April 11th, 1919, Detroit Board of Commerce. Paper: "Direct Current Motors" by John C. Parker. Attendance 42.

Fort Wayne.—March 20, 1919, G. E. Assembly Room. Paper: "Some Electrical Developments Brought about by the War," by C. I. Hall. Attendance 27.

Indianapolis—Lafayette.—March 3, 4 and 5, 1919, Purdue University. Addresses as follows—1. "Systems of Handling and Recording Trouble" by V. N. Gregg; 2. "Maintenance of Central Office Equipment" by Frank X. Staub; 3. "Maintenance of Outside Plant" by F. M. Hodgson; 4. "The Engineering Department of the Public Service Commission" by H. O. Garman; 5. "Recent Developments in Central Office Equipment" by C. A. Breese; 6. "Some Experiences in Cutting Over a Large Manual to Automatic Plant" by H. W. Munsell; 7. "Electrolysis" by L. G. Bischoff; 8. "Cable Construction" by W. M. Van Nostran; 9. "Types of Construction for Rural Lines" by L. W. Connarroe. Attendance 125.

March 21, 1919, Athenaeum of Indianapolis. Subject: "Nitric Acid from the Air." Speakers: Profs. C. Francis Harding, F. O. Anderegg and K. B. McEachron. Attendance 45.

Ithaca.—March 14, 1919, Franklin Hall, Cornell University. Paper: "Problems in High-Tension Power Transmission with Special Reference to Conditions in Ontario" by W. P. Dobson. Attendance 68.

Lynn.—March 26, 1919, G. E. Hall. Lecture by Mr. E. F. W. Alexanderson on "Trans-Oceanic Radio Communication." Attendance 175.

Madison.—April 10, 1919, Auditorium, Engineering Building. Papers: "Recent Developments in Electric Lighting" by W. M. Skiff; "The Industrial Lighting Code of Wisconsin" by John A. Hoeveler. Attendance 55.

Milwaukee.—March 19, 1919, Athletic Club. Addresses by Mr. Duncan Watson, Alderman of London, England, on "Electrical Problems Confronting the Authorities at London," and by Mr. J. R. Watson on "Synchronous Motors." Attendance 160.

Pittsburgh.—March 11, 1919, Chamber of Commerce Auditorium. Paper: "Electric Furnace Application and Control" by J. A. Seede. Attendance 126.

April 8, 1919, Chamber of Commerce Auditorium. Paper: "The New Pittsburgh Office of the Western Union Telegraph Company" by G. H. Kendrick. Attendance 130.

Pittsfield.—March 12, 1919, New American Hotel. Lecture by Dr. C. P. Steinmetz on "Soap Bubbles." Attendance 175.

March 27, 1919, New American Hotel. Paper: "Trans-Oceanic Radio Communication" by E. F. W. Alexanderson. Attendance 125.

Rochester.—February 28, 1919, Rochester Engineering Society Rooms. Paper: "Heat Treatment of Steel" by Samuel W. Miller. Paper illustrated by lantern slides. Attendance 58.

March 28, 1919, Rochester Engineering Society Rooms. Paper: "Electric Furnaces and Electric Welding" by H. A. Winne. Attendance 76.

San Francisco.—March 28, 1919, Engineers Club. Paper: "Mountain Railroad Electrification in California" by W. F. Dietrich. Attendance 70.

Schenectady.—March 21, 1919, Edison Club Hall. Illustrated lecture by Prof. F. H. Sexton on "Industrial Reestablishment of War Cripples." Attendance 165.

April 4, 1919, Edison Club Hall. Address by Col. Jas. M. Andrews on "Overseas Service with the 105th." Attendance 625.

Spokane.—March 21, 1919, Chamber of Commerce. Paper: "Magnesite, Its Geology, Products and Their Uses" by C. D. Dolman. Attendance 37.

St. Louis.—March 26, 1919, Union Electric Building. Address by the Hon. Selden P. Spencer, U. S. Senator from Missouri, on "The League of Nations." Attendance 125.

Toledo.—February 27, 1919, Park Exchange, Ohio State Tel. Co. Address by Mr. E. H. Brown on "The Growth and Development of the Park Exchange." Attendance 21.

March 27, 1919. Toledo Commerce Club. Address by Mr. E. B. Thurston on "The General Operation of Electric Elevators." Attendance 19.

Toronto.—March 21, 1919, Engineers Club Paper: "Storage Batteries" by J. Lester Woodbridge. Paper illustrated by lantern slides. Attendance 85.

April 4, 1919, Engineers Club. Address by Mr. G. D. Leacock on "Early Experiences in the Electrical Business in Canada." Attendance 95.

April 11, 1919, Westinghouse Auditorium, Hamilton, Ontario. Paper: "The Development of the Electric Drive in Steel Mills" by G. E. Stoltz. Joint meeting with Hamilton Branch of Engineering Institute of Canada. Attendance 175.

Washington.—April 8, 1919, Cosmos Club. Illustrated address by Mr. W. D. Ryan on "Illumination, Ancient and Modern." Attendance 139.

PAST BRANCH MEETINGS

University of Cincinnati.—March 27, 1919, Engineering Building. Paper: "Fire Control in the U. S. Coast Artillery" by F. W. Huss. Attendance 45.

Georgia School of Technology.—March 5, 1919, Chapel. Motion pictures showing the production in the various shops of the General Electric Company. The pictures were explained by Mr. G. H. Pfeif. Attendance 55.

March 13, 1919.—Chapel. Address by Mr. E. F. McLaughlin on "Railway Electrification." Motion picture "The King of the Rails." Attendance 65.

University of Kentucky.—March 26, 1919, Mechanical Hall. Addresses on Aeronautics by Messrs. J. E. McClellan and R. S. Arnold. Attendance 24.

Massachusetts Institute of Technology.—April 10, 1919. Paper: "High-Frequency Oscillations" by Prof. G. W. Pierce. Attendance 115.

University of Missouri.—March 24, 1919, Engineering Building. Paper: 1. "Rates and Rate Making" by F. Shelton; 2. "Radio Development During the War" by F. Leach. Attendance 19.

April 7, 1919, Engineering Building. Papers: 1. "Insulation of High-Tension Transformers" by B. H. Wigbels, Jr.; 2. "Use of Electricity in Irrigation" by B. Fleshman. Election of officers as follows—chairman, A. C. Lanier; vice-chairman, J. H. Koester; asst. secretary, W. L. Jones, corresponding secretary, W. H. Moore; Treasurer, B. Fleshman. Attendance 20.

Montana State College.—March 19, 1919, Electric Building. Lecture by Mr. F. M. Redman on "The Use of Electricity in Ship Building." Election of officers as follows—chairman, Jas. M. McElwee; Secretary, J. A. Thaler. Attendance 24.

April 3, 1919, Physics Lecture Room. Illustrated address by Mr. W. F. Coors on "Electrification of The Milwaukee Railroad." Attendance 31.

University of Nebraska.—April 3, 1919. Paper: "Practical Electrical Problems" by L. W. Anderson. Attendance 14.

April 10, 1919, Mechanical Engineering Building. Addresses as follows—1. "Engineering as a Business" by J. E.

Harsh; 2. "The Electrification of the Panama Canal" by F. H. McKinney. Attendance 39.

University of North Carolina.—April 8, 1919, Chapel Hill. Papers: 1. "Corporation vs. Partnership" by J. H. Mustard; 2. "Service" by H. B. Shaw. Attendance 36.

North Carolina State College.—February 17, 1919. Illustrated lecture by Mr. A. L. Humphrey on "The Operation and Adjustment of Commercial Watt-Hour Meters."

Ohio Northern University.—March 19, 1919, Dukes Memorial. Address by Prof. F. L. Berger on "The Ideal Student of Engineering." Attendance 13.

April 3, 1919, Dukes Memorial Papers: 1. "Transportation in New York City" by Monroe Zimmerman; 2. "Opportunities for Electrical Development in South America" by O. Towares. Attendance 16.

Ohio State University.—March 21, 1919, Robinson Laboratory. Lecture by Prof. C. A. Wright on "Character Analysis as Applied to the Engineer." Attendance 26.

April 2, 1919. Demonstrations of (a) Shaffer Prone and Pressure Method of Resuscitation from Electrical Shock, and (b) Lungmotor as Used in Resuscitation." Attendance 41.

Pennsylvania State College.—March 10, 1919. Addresses as follows—1. "Electric Headlights for Locomotives" by G. E. Schweitzer; 2. "Illumination" by D. L. Markle. Election of officers as follows—president, E. W. Taylor; vice-president, C. A. Nelson; secretary, C. K. Mast; treasurer, J. L. Weaver; assistant treasurer, E. L. Schlotters; sergeant at arms, C. M. Skooglund.

March 24, 1919. Illustrated lecture on "Remote Control" by Dr. Woodruff.

April 7, 1919. Addresses as follows—1. "Hydro-Electric Plants" by Dean Sackett; 2. "Illumination" by D. L. Markle.

University of Pittsburgh.—March 14, 1919. Address by Mr. N. E. Bonn on "The Measurement of Very Short Intervals of Time by Electricity." Attendance 19.

March 28, 1919. Illustrated address by Mr. G. M. Hiles on "The Methods of Balancing of Rotors." Attendance 14.

Purdue University.—March 18, 1919, Electrical Building. Addresses as follows—1. "Experiences in Training Camp and the Trip to France" by Lieut. C. P. Boggs; 2. "Gossport System of Instruction for Aviation" by Lieut. E. K. Goss; 3. "System of Instruction in Flying as Given in France and England" by Lieut. Bernard Schultz. Attendance 70.

Rensselaer Polytechnic Institute.—March 11, 1919, Sage Laboratory. Address by Dr. M. A. Hunter on "The Chemistry of Gas Warfare." Election of officers as follows—chairman, W. J. Williams; secretary, L. B. Raynor. Attendance 75.

April 15, 1919. Paper: "Electricity in Shipbuilding" by Dr. W. L. Robb. Attendance 76.

Throop College of Technology.—March 13, 1919. Address by Mr. A. L. Klein on "Aeroplane Engines, with Special Reference to Liberty Engine." Attendance 25.

University of Virginia.—March 28, 1919, Electrical Laboratory. Papers: 1. "Uses of Electricity" by W. W. Boyd 2. "Automatic Stokers" by W. McN. Gilchrist; 3. "Paper Mill Machinery" by P. B. Bass. Attendance 18.

April 16, 1919, Peabody Hall. Motion pictures as follows—1. "Sugar Industry in Cuba;" 2. "Electrical Giant;" 3. Fairy Magic;" 4. "Electrification of Steam Railways." Attendance 78.

Virginia Polytechnic Institute.—March 12, 1919. Illustrated lecture by Mr. A. W. Fairer on "The Electrification of Steam Railroads." Attendance 37.

April 8, 1919. Motion pictures on "Cane Sugar Production in Cuba", and "The Construction of the Largest Alternator in the World." Attendance 52.

Washington University.—February 25, 1919. Paper: "Electric Control Apparatus" by G. W. Pickson. Attendance 29.

ASSOCIATES ELECTED APRIL 11, 1919

Alden, Fred N., Lieutenant, Department Signal Office, U. S. Army, Fort Sam Houston, Texas.

***Alexander, Clarence F.**, Engineer, Western Electric Company, Inc., 463 West St., New York, N. Y.

Alexander, Don M., Manager, Alexander Electric Co., 108 S. Howard St., Spokane, Wash.

Allen, Ebben S., Engineering Asst., New York Telephone Co., New York; res., 1362 E. 17th St., Brooklyn, N. Y.

Allen, Frederick J., Accountant and Manager, Benjamin Electric Co.; res., 7 Duggan Avenue, Toronto, Ont.

Angel, Claude W., General Foreman, Electrical Construction, Interborough Rapid Transit Co., 600 W. 59th St., New York; res., Elmhurst, N. Y.

Arnar, Otto B., Business Manager and Electrical Engineer, Reykjavik, Iceland.

Baerresen, Albert W., Instructor, Educational Dept., The Mountain States Tel. & Tel. Co.; res., 1665 Madison St., Denver, Colo.

Banan, Horace Frederick, Engineer, D. &. S. Div., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 522 Holmes St., Wilkinsburg, Pa.

Baring, John W., Testing Engineer, Commonwealth Edison Co.; res., 736 N. Lotus Ave., Chicago, Ill.

Barnett, David Alva, Engr. in Charge of Elec. Construction, Air Nitrates Corp., Muscle Shoals, Ala.

Barrozo, Rubem Ferreira, Repair & Construction Work; res., Rua Pinto de Azevedo 12, Rio de Janeiro, Brazil, S. A.

Baunach, Robert P., Jr., Supervisor of Electrolysis, New York Telephone Co.; res., 49 Chelsea Ave., Newark, N. J.

Bellerjeau, William Y., Engineering Asst., New York Telephone Co., 15 Dey St., New York, N. Y.; res., Fanwood, N. J.

Berkshire, William Thomas, Designing Engineer, General Electric Co.; res., 12 North Ferry St., Schenectady, N. Y.

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COOPER, LEO H., District Manager, Frank Adam Electric Co., Minneapolis, Minn.

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TRANSFERRED TO THE GRADE OF FELLOW APRIL 11, 1919

ADDICKS, LAWRENCE, Consulting Engineer, New York, N. Y.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its regular monthly meeting, held on April 7, 1919, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

BODLER, OSCAR W., Electrical Engineer, Eastman Kodak Co., Rochester, N. Y

SQUIER, GEORGE O., Major-General, Chief Signal Officer, War Department Washington, D. C.

To Grade of Member

BORDEN, PERRY A., Instrument Engineer, Hydro-Electric Laboratories, Toronto, Ont.

Brooks, Henry W., Senior Lieut., U. S. N. R., Chief, Machinery Section, Bureau of Ordnance, Navy Dept., Washington, D. C.

Brooks, Herbert B., Physicist, Bureau of Standards, Washington, D. C.

Coors, William F., Sales Engineer, General Electric Co., Butte, Mont.

Ewart, Frank R., Construction Engineer, Ewart & Jacob, Toronto, Ont.

Holcombe, Ernest S., Electrical Construction Engineer, Interborough Rapid Transit Co., New York, N. Y.

Josephs, Lyman C. **Jr.**, Engineer, International Motor Co., New York, N. Y.

Mullergren, Arthur L., Sec'y & Treasurer, Benham Engineering Co., Oklahoma City, Okla.

Tibbals, Emerson C., Electrical Engineer, Atlantic Loading Co., New York, N. Y.

Westbrook, Francis A., Engineering Dept., Habirshaw Electric Cable Co., New York, N. Y.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before May 31, 1919.

Ackhurst, J. E., Halifax, N. S.
Adams, C. C., (Member), Chicago, Ill.
Adams, C. C., Phoenix, Ariz.
Aldous, E. E., Denver, Colo.
Amy, E. V., New York, N. Y.
Anthony, A. W., Jr., Brockton, Mass.
Arff, N., Portland, Ore.
Armington, R. L., Boston, Mass.
Atkinson, J. E., Seattle, Wash.
Bacon, V. R., Omaha, Neb.
Bandorf, W., Baltimore, Md.
Barber, H. C., Toronto, Ont.
Barker, R. J., Rochester, N. Y
Barry, R. L., Cincinnati, Ohio.
Barth, E. A., Great Lakes, Ill.
Beck, R. J., St. Louis, Mo.
Bercaw, O. M., Chicago, Ill.
Berry, W. J., Brooklyn, N. Y.
Bocher, A. C., Milwaukee, Wis.
Bonnivier, C. M., Quincy, Mass.
Bothwell, C. C., Toronto, Ont.
Bretch, E., (Member), St. Louis, Mo.
Brooks, S. C., Springfield, Mass.
Brown, C. C., Franklin, N. J.
Brown, R. B. J., New York, N. Y.
Brown, S. K., Washington, D. C.
Brown, W. M., Pueblo, Colo.
Brush, C. W., Brooklyn, N. Y.
Burton, J. S., Seattle, Wash.
Butcher, L. M., Denver, Colo.
Byrne, F. T., Rochester, N. Y.
Cady, W. G., (Member), Middletown, Conn.
Cain, J. C., Portland, Ore.
Camden, W. A., Pittsburgh, Pa.
Careless, W. R. S., Toronto, Ont.
Chamberlin, J. N., San Francisco, Cal.
Champ, C. A., Chicago, Ill.
Chandlee, J. M., St. Louis, Mo.
Chandler, F. H., Toronto, Ont.
Chartrand, J. B., St. Louis, Mo.
Clark, A. T., Toronto, Ont.
Codding, H. W., Newark, N. J.
Coit, N. H., Auburn, Neb.
Cochrane, W. J., Toronto, Ont.
Connolly, H. T., (Member), Annapolis, Md.
Connor, A. P., Holyoke, Mass.
Cooch, H. A., Toronto, Ont.
Cook, S. S., St. Catharines, Ont.
Corlett, F. M., Dallas, Texas.
Crane, C. O., Boise, Idaho.
Crowley, J. W., Baltimore, Md.
Curry, G. P., Hiawatha, Utah.
Cutts, F., (Member) New Haven, Conn.
Dierken, J. H., Washington, D. C.
Dillon, S. J., Camden, N. J.
Doan, G. H., Detroit, Mich.
Dorfman, L., E. Pittsburgh, Pa.
Douglass, W. E., (Member), E. Pittsburgh, Pa.
Driver, E. T., Toronto, Ont.
Drummond, R. S., Chicago, Ill.
Du Bois, C. G., (Member), New York, N. Y.
Duffy, G. L., (Member), Seattle, Wash.

Duke, R. A., Baltimore, Md.
Edsall, W. S., (Member), Brooklyn, N. Y.
Edwards, C. W., Durham, N. C.
Fake, F. C., Portland, Ore.
Falk, A. H., Boston, Mass.
Faught, R. C., Baltimore, Md.
Fein, I. J., Bluefield, W. Va.
Ferguson, C. B., Boston, Mass.
Fink, L., Hoboken, N. J.
Finnie, H. V., St. Catharines, Ont.
Fisher, W. C., (Member), Mt. Vernon, N. Y.
Flannery, D. T., Niagara Falls, Ont.
Flint, T. R. C., Toronto, Ont.
Floyd, G. D., Toronto, Ont.
Forbes, A., Portland, Ore.
Freedman, L. W., New York, N. Y.
Freitang, F. J., Kearny, N. J.
Frenger, R. F., Chicago, Ill.
Freese, A. C., Pueblo, Colo.
Frutig, L. H., New York, N. Y.
Galyan, E. O., St. Louis, Mo.
Gamble, S. E., San Francisco, Cal.
Gerald, A. H., Chicago, Ill.
Goetz, H. D., Crosby, N. Dakota.
Going, L. W., Portland, Ore.
Grace, G. E., Bridgeport, Conn.
Gram, J. I., Niagara Falls, Ont.
Greene, A. N., St. Louis, Mo.
Greene, P. A., Brooklyn, N. Y.
Greenshields, W. R., Toronto, Ont.
Griffith, A., Pueblo, Colo.
Gritzan, L. LeR., Baltimore, Md.
Gromaskie, P. J., Pittsburgh, Pa.
Groome, F. T., Toronto, Ont.
Grover, L. E., New York, N. Y.
Gruber, H. D., Bethlehem, Pa.
Gumm, L. M., Chicago, Ill.
Hare, R. A., St. Catharines, Ont.
Harries, H. D., (Member), Chicago, Ill.
Harrington, J. L., Baltimore, Md.
Harris, J. A., Toronto, Ont.
Hawkins, R. A., (Member), Sonora, Mexico
Hedin, W. F., Portland, Ore.
Heinrich, W. A., St. Louis, Mo.
Helwig, E. C., New York, N. Y.
Hill, C. F., N. Boston, Mass.
Hinman, L. E., Portland, Ore.
Hoge, C. H., Seattle, Wash.
Hoisington, N. P., Philadelphia, Pa.
Holman, L. H., Toronto, Ont.
Howes, F. J., (Member), Rochester, N. Y.
Huebner, G., Topeka, Kansas.
Humphrey, K. B., New York, N. Y.
Hunker, W. L., St. Louis, Mo.
Hurlock, H. T., Boston, Mass.
Ink, J. B., Boston, Mass.
Jackson, J. B., Youngstown, Ohio
Jeans, J. H., St. Louis, Mo.
Jeffries, D. C., Indianapolis, Ind.
Jensen, C. H., E. Pittsburgh, Pa.
Jensen, W. H., Chicago, Ill.
Jewett, P. L., Kerto, Cal.
Johnson, F. M., Chicago, Ill.
Johnson, H. J., St. Louis, Mo.
Johnson, O. F., San Francisco, Cal.
Jones, H. R., Pueblo, Colo.
Jones, J. S., (Member) New York, N. Y.
Jones, R. L., Oakland, Cal.
Keiser, W., Hartford, Conn.
Kightley, F. W., Toronto, Ont.
Kindermann, L. F., Bayonne, N. J.
Kirby, N. R., Toronto, Ont.
Knapman, A. J., Hamilton, Ont.
Knotts, C. L., E. Pittsburgh, Pa.
Knudsen, C. B., Rochester, N. Y.
Kolster, F. A., (Member), Washington, D. C.
Kruel, A. H., Portland, Ore.
Kues, W. C., Wilmington, Del.
Lake, N. J., Guelph, Ont.
Landwehr, J. H., St. Louis, Mo.
Lange, E. O., Madison, Wis.
Langford, L. C., Toronto, Ont.
Lansche, O. A., Baltimore, Md.
Leggett, J. M., Schenectady, N. Y.
Leidig, L. J., Steelton, Penn.
Leonard, M. W., Newark, N. J.
Lescarbours, A. C., New York, N. Y.
Leslie, J. N. M., Toronto, Ont.
Ligon, G. C., Baltimore, Md.
Lippincott, D. K., (Member) San Francisco, Cal.
Locke, E. R., W. Lynn, Mass.
Lohr, H., Arnhem, Holland.
Long, M. B., Washington, D. C.
Ludwig, J. C., Pittsfield, Mass.
Lutz, R. A., Chicago, Ill.
Mackeown, S. S., Washington, D. C.
Mackillop, D. A., Kansas City, Mo.
Maddox, G. F., Chicago, Ill.
Martin, J. E., Hoboken, N. J.
Mather, R. H., Montreal, Que.

Mayer, W. S., Philadelphia, Pa.
Mayo, R. E., Lynn, Mass.
Meredith, G. E., Kansas City, Mo.
Metzger, R. A., Cincinnati, Ohio.
Mitchell, B. A., (Member) Garfield, Utah.
Mitschrich, M. F., St. Louis, Mo.
Miwa, T., Los Angeles, Cal.
Moore, L. P., Wilmington, Del.
Murray, E. W., Toronto, Ont.
Myrick, J. D., Baltimore, Md.
McCabe, G. B., Detroit, Mich.
McCune, H. A., Washington, D. C.
McDowell, T. D., Chicago, Ill.
McKean, A. H., E. Pittsburgh, Pa.
McManus, C. B., Birmingham, Ala.
Nag, N. K., Chicago, Ill.
Nankivell, F. J., Long Island City, N.Y.
Neal, G. A., Hammond, Ind.
Neill, W. T., Salem, Ore.
Nelson, H. J., Seattle, Wash.
Newberry, A. P., Dieringer, Wash.
Noble, P. O., Schenectady, N. Y.
Norton, C. F., (Member) Howell, Mich.
Nyman, A., E. Pittsburgh, Pa.
O'Meara, F. E., St. Louis, Mo.
O'Neil, R. D., Tacoma, Wash.
Owen, H. A., Toronto, Ont.
Parker, W. P., Dunkirk, N. Y.
Parmelee, F. A., Pueblo, Colo.
Parsons, E. S., Phillipsdale, R. I.
Petersen, M., St. Louis, Mo.
Pfleger, G. T., Los Angeles, Cal.
Pillsbury, E. S., (Member), St. Louis, Mo.
Potter, C. P., St. Louis, Mo.
Powers, M. D., Niagara Falls, N. Y.
Pratt, H. H., Wilkes-Barre, Pa.
Quinn, J. F., New York, N. Y.
Rader, H., Philadelphia, Pa.
Rammling, C. J., Syracuse, N. Y.
Reese, P. J., St. Louis, Mo.
Reihmer, L. L., Chicago, Ill.
Reque, S. G., Allentown, Pa.
Richards, V. J., Portland, Ore.
Richey, J. L., McAllen, Texas.
Robertson, E. B., E. Pittsburgh, Pa.
Romaine, W. R., Jr., New York, N. Y.
Roe, F. S., E. Pittsburgh, Pa.
Rogers, F. O., Dieringer, Wash.
Rundle, L. P., St. Catharines, Ont.
Russell, H. A., Toronto, Ont.
Russell, W. E., Toronto, Ont.
Sadler, E. K., Battle Mountain, Nev.
Sanderson, W. D., Detroit, Mich.
Schermerhorn, H. L., Schenectady, N. Y.
Schick, C. S., Erie, Pa.
Schoonmaker, L. E., Orange, N. J.
Scoville, G. L., San Francisco, Cal.
Sears, G. C., Dieringer, Wash.
Seeley, W. J., New London, Conn.
Sharland, G. A., St. Paul, Minn.
Shaw, H. E., E. Pittsburgh, Pa.
Shaw, J. S., St. Louis, Mo.
Shepherd, R. R., (Member), Indiana Harbor, Ind.
Sheridan, F. J., Chicago, Ill.
Sherwood, L. M., Baltimore, Md.
Shuck, G. R., (Member), Seattle, Wash.
Skinner, B. H., Chicago, Ill.
Small, V. E., Seattle, Wash.
Smith, E. A., Miami, Fla.
Smith, H. J., Pittsburgh, Pa.
Smith, R. L., (Member), Winchendon, Mass.
Smith, W. E., Brooklyn, N. Y.
Snow, L. D., Seattle, Wash.
Speaker, C., Washington, D. C.
Spencer, T. J., Dieringer, Wash.
Spiller, P., Kearny, N. J.
Stark, J. R., (Fellow) Racine, Wis.
Strassner, F. J., Newark, N. J.
Sturges, I. B., Portland, Ore.
Swenson, G. W., Minneapolis, Minn.
Taketa, S., Philadelphia, Pa.
Taylor, A. H., Washington, D. C.
Taylor, E. C., (Member) Los Angeles, Cal.
Taylor, H. B., Detroit, Mich.
Thompson, B. F., Baltimore, Md.
Thompson, E. V., Racine, Wis.
Thompson, H. C., St. Louis, Mo.
Thrasher, W. A., Toronto, Ont.
Tidd, G. W., Marion, Ala.
Tigerman, J. H., San Francisco, Cal.
Tighe, L. G., (Member), Akron, O.
Tobias, A., Washington, D. C.
Treffinger, H. H., Baltimore, Md.
Turner, W. D., Pueblo, Colo.
Ultsch, H., New York, N. Y.
Van Emden, A. L., Boston, Mass.
Veeder, W. J. G., Chicago, Ill.
von Heinburg, F. H., Schenectady, N.Y.
Walker, E. M., Terre Haute, Ind.
Wallace, J., Toronto, Ont.

Walsh, W. J., Butte, Mont.
Warren, W. H., San Francisco, Cal.
Warris, J. F., San Francisco, Cal.
Washington, L. S., St. Louis, Mo.
Wauchop, J. M., Teele, Utah.
Wayman, P. F., Toronto, Ont.
Webb, R. T., St. Louis, Mo.
Wells, A. R., Toronto, Ont.
Wells, J. M., Riverside, Cal.
Wentworth, A. S., Baltimore, Md.
Wiley, C. M., New York, N. Y.
Wills, J. C., Toronto, Ont.
Wilson, N. P., Seattle, Wash.
Wright, E. L., Pittsfield, Mass.
Wyer, G. R., Toronto, Ont.
Total 277

Foreign

Dale, W. J. E., (Fellow), Havana, Cuba.
de Velazco, J. F., Havana, Cuba
Elliott, F. F., London, S. W. 8, Eng.
Holbrook, H. S., Rugby, Eng.
Dean, H., Mansfield, Eng.
Kilpatrick, J. G., Melbourne, Aus.
Nakao, K., Tokyo, Japan.
Quackenbush, E. F., (Fellow), Havana, Cuba.
Seeley, C. G., Melbourne, Aus.
Thomson, J. A., (Member), Havana, Cuba.
White, J. W., Havana, Cuba.
Total 11

STUDENTS ENROLLED APRIL 11, 1919

10151 Dobbie, P. A., Cooper Union
10152 Weaver, J. L., Penn. State Coll.
10153 Anchor, C. J., Bucknell Univ.
10154 Gagliardi, F. G.
10155 Huber, R. E., Univ. of Notre Dame
10156 Sidenfaden, O. L., Univ. of Notre Dame
10157 Warren, H. S., Univ. of Ariz.
10158 O'Connor, E. J., Univ. of Notre Dame
10159 McCarthy, J. F., Univ. of Notre Dame
10160 Kissel, J. H., N. Y. Elec. School
10161 Arends, R. G., Univ. of Notre Dame
10162 Bochenek, D. M., Ohio No. Univ.
10163 Hoffmann, L. B., New Hampshire State Coll.
10164 Wolfe, J. C., Univ. of Pittsburgh
10165 Gardner, G. A., Univ. of Pittsburgh
10166 Kennedy, L. P., Univ. of Pittsburgh
10167 McCarty, R. S., Univ. of Pittsburgh
10168 Bonn, N. E., Univ. of Pittsburgh
10169 Hiles, G. McC., Univ. of Pittsburgh
10170 Applegate, L. M., Univ. of Wash.
10171 Engquist, V. E., Univ. of Minn.
10172 Lovatt, H. S., Drexel Inst.
10173 Liu, A. S., Drexel Inst.
10174 Keller, J. F., Univ. of Pittsburgh
10175 Chan, H. Q., Univ. of Pittsburgh
10176 Angel, H. H., Bucknell Univ.
10177 Leinbach, A. R., Penna. State Coll.
10178 Mast, C. K., Penna. State Coll.
10179 Hall, V. B., Bucknell Univ.
10180 Simon, M. W., Engg. School of Milwaukee
10181 Bee, E. S., Ga. School of Tech.
10182 Neims, J. G., Ga. School of Tech.
10183 Cockrill, S. B., Ga. School of Tech.
10184 Jerger, W. D., Ga. School of Tech.
10185 Milner, S. W., Ga. School of Tech.
10186 Reese, W. M., Jr., Ga. School of Tech.
10187 Pollard, W. R., Ga. School of Tech.
10188 Betts, R. B., Ga. School of Tech.
10189 Tanner, W. M., Ga. School of Tech.
10190 McPherson, C. M., Ga. School of Tech.
10191 Hitt, A., Ga. School of Tech.
10192 Wilson, C. B., Ga. School of Tech.
10193 Hilley, R. D., Ga. School of Tech.
10194 Smith, J. L., Ga. School of Tech.
10195 Garrett, H. O., Ga. School of Tech.

10196 Manning, G. E., Ga. School of Tech.
10197 Robinson, J. M., Ga. School of Tech.
10198 Fraser, G. R., Ga. School of Tech.
10199 Wallace, S. S., Jr., Ga. School of Tech.
10200 Ballard, E. D., Ga. School of Tech.
10201 Crumley, H. L., Jr., Ga. School of Tech.
10202 McMurry, J. A., Ga. School of Tech.
10203 Powers, H. C., Ga. School of Tech.
10204 Skeen, J. H., Ga. School of Tech.
10205 Smith, I. H., Ga. School of Tech.
10206 Smith, W. D., Ga. School of Tech.
10207 Revitch, N. C., N. Y. Elec. School
10208 Lucas, H. C., Bucknell Univ.
10209 Buchan, C. E., School of Engg. of Milwaukee.
10210 Wickus, R. W., School of Engg. of Milwaukee
10211 Davis, E. N., School of Eng. of Milwaukee
10212 Virtue, W. D., Univ. of Mo.
10213 Sullivan, G. L., Univ. of Notre Dame
10214 Bersey, W. S., Mich. Agr. Coll.
10215 Bazzeghin, Yale Univ.
10216 Illg. R. S., Armour Inst. of Tech.
10217 Lawler, J. P., Syracuse Univ.
10218 Blaich, W. J., Jr., Syracuse Univ.
10219 Keilien, S., Syracuse Univ.
10220 Lyons, W., Univ. of Cal.
10221 Silent, H. C., Univ. of Cal.
10222 Muenter, R. H., Univ. of Cal.
10223 Tenney, G. C., Univ. of Cal.
10224 Parham, D. L., School of Engg. of Milwaukee
10225 Weeden, B. F., School of Engg. of Milwaukee
10226 Laughlin, C. W., Univ. of Mo.
10227 Marston, W. L., Univ. of Penn.
10228 Melhuish, L. E., State Coll. of Pa.
10229 Ryder, M. P., Univ. So. Cal.
10230 Herschey, C. G., Univ. of Ariz.
10231 Reitz, H. J., Montana State Coll.
10232 Atkinson, T. H., Swarthmore Coll.
10233 Snow, H. A., Geo. Washington Univ.
10234 St. Bernard, L. F., Toronto Tech. Inst.
10235 Pruett, J. W., Ala. Poly. Inst.
10236 Shafer, J. E., Penn. State Coll.
10237 Ruzek, O. E., Univ. of Notre Dame
10238 Neuses, A. W., Univ. of Notre Dame
10239 Reid, J. M., Univ. of NotreDame
10240 Jones, L., Bucknell Univ.
10241 Skidmore, J. R., Casino Tech. Night School.
10242 Postles, F. J., N. Y. Elec. School
10243 Lincoln, J. C., N. Y. Elec. School
10244 Morgan, W. J., Univ. of Cincinnati
10245 Trumble, L. A., Ohio No. Univ.
10246 Fonseca, P. Q., Ohio No. Univ.
10247 Risk, G., Jr., Catholic Univ. of America
10248 Kasparek, F. P., School of Engg. of Milwaukee
10249 Oddie, H. W., Univ. of Utah
10250 Mitchell, D. P., Tri-State Coll.
10251 Deal, H. B., Mass. Inst. of Tech.
10252 Soars, E. A., Mass. Inst. of Tech.
10253 Smiddy, H. F., Mass. Inst. of Tech.
10254 Wilson, I. H., Mass. Inst. of Tech.
10255 Fogler, F., Mass. Inst. of Tech.
10256 Booth, R. D., Mass. Inst. of Tech.
10257 Sahlmann, F. L., Kans. State Agr. Coll.
10258 Williamson, E. T., Kans. State Agr. Coll.
10259 Downer, C. B., Kans. State Agr. Coll.
10260 Singleton, L. W., Johns Hopkins Univ.
10261 Douglass, W. J., Univ. of Notre Dame
10262 Johnson, K. W., School of Engg. of Milwaukee
10263 Searle, W. J., Jr., Penna. State Coll.

Total 113

PERSONAL

P. LE ROY FLANSBURG, electrical engineer, formerly with the E. I. du Pont de Nemours and Company in charge of the Safety and Efficiency departments at their Haskell, N. J. plant has just accepted a similar position with the Benjamin Eastwood Company of Paterson, N. J.

IRVING SAMUELS has established offices in the Hunsicker Bldg., Allentown, Pa., as an Electrical and Mechanical Sales Engineer and Manufacturers' Agent. Mr. Samuels served as efficiency engineer for the Lehigh Valley Transit Co., in 1913 became distribution engineer for the Lehigh Valley Light and Power Co. and in July, 1918 accepted a position as electrical engineer for the Air Nitrates Corporation in New York.

J. M. SMITH has resigned the position of Managing Engineer of the Triumph Electrical Company of Cincinnati to accept an important post with the Texas Company.

OBITUARY

HARRY LE ROY CURTIS chief electrical engineer of the International Paper Company recently died. Mr. Curtis was a graduate of Cornell, class 1907. He immediately entered the testing department of the G. E. Co. where he remained one year and then became associated with the Minnesota and Ontario Power Co. at International Falls, Minn. In 1910 he entered the employ of the International Paper Co. and remained with them until September 1917 at which time he went to Washington as trade adviser to the War Trade Board in charge of paper mill and electrical engineering matters. When this body disbanded he returned to the International Paper Co. Mr. Curtis became an Associate in the Institute in 1909.

CAPTAIN STUART THOMSON died on March 23, 1919 of pneumonia. Captain Thomson, son of Dr. Elihu Thomson, after graduating from Harvard in 1908 took special work at M. I. T. and in 1909 entered the employ of the G. E. Co. with whom he remained until he entered the Army in the Ordnance Dept. He became an Associate in the Institute in 1912.

GEORGE E. CLAFLIN, Vice-President of the Electric Bond and Share Company died suddenly on April 18, 1919 at Atlantic City. Mr. Claflin was one of the pioneer electrical engineers of the country. He entered the employ of the Westinghouse E. & M. Co. in 1888 and installed some of the earliest electric generating stations in the country. The Franklin Electric Co. of Kansas City, Mo. was one of Mr. Claflin's early ventures, later he entered consulting engineering. In 1904 he became associated with the United Electric Securities Co. of Boston and in 1912 became Vice President of the Electric Bond and Share Co. Mr. Claflin became an Associate in the Institute in 1905 and was transferred to Member in 1909.

LIEUTENANT EARL G. ANDERSON'S death has just been confirmed by the War Dept. He died on July 15, 1918 in a hospital in France as a result of wounds. Lieut. Anderson at the time of entering the Army was a cadet engineer with H. L. Doherty & Co. He became an Associate in the Institute in 1916.

LIEUTENANT R. M. WILSON, 7th Engineers, A. E. F., formerly with the Puget Sound Traction, Light & Power Co. was killed in France as described in the following extract of a letter from his commanding officer, Major Hoge to his mother.

"It was the morning of the 14th of October that your son was wounded. This division was attacking that day on the Argonne front between Cunel and Romagne, Dept. of the Meuse. Richard had been given command of F Company of this regiment only a week or so previous to this. His company was ordered to go "over the top" with the first wave of the infantry. They were carrying small footbridges which were to be used in crossing a stream in their front. It was while leading his men on this mission that your son was struck in the stomach by a machine gun bullet. He was taken to a first aid station at La Ferme de Madeleine as soon as possible and died at that place shortly afterwards. He was buried in the Soldiers' Cemetery at this place by the Chaplain of the Sixth Infantry."

ADDRESSES WANTED

Any reader knowing the present address of any of the following members is requested to communicate with the Secretary at 33 West 39th Street.

L. A. Carbo
(former address)
1614 Eye St. N. W.,
Washington, D. C.

O. A. Darnell
(former address)
412 E. 5th St.,
Los Angeles, Cal.

D. G. Davis
(former address)
55 Hanson Place,
Brooklyn, N. Y.

George H. Groce
(former address)
2857-59 S. Halsted St.,
Chicago, Ill.

J. E. Penn
(former address)
322 Champlain Ave.,
Cleveland, Ohio.

Geo. B. Pulham
(former address)
General Post Office
San Francisco, Cal.

Arthur P. Stephens
(former address)
Floral Park,
Wilkinsburg, Pa.

L. L. Summers
(former address)
1520-18th St.,
Washington, D. C.

E. W. Sundberg
(former address)
6912 Page Ave.,
St. Louis, Mo.

ENGINEERING SERVICE BULLETIN

Opportunities.—The Institute, is particularly anxious to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in this BULLETIN. The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Services Available.—Under this heading brief announcements (not more than fifty words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office files.

Note.—Copy for publication in the BULLETIN should reach the Secretary's office not later than the 20th of the month if publication in the following issue is desired. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

Engineering Societies Employment Bureau.—This is a joint bureau under the auspices of the Engineering Council. The Institute's employment service is coordinated with that of the joint bur eau.

OPPORTUNITIES FOR SERVICE

V-502. Draftsman. Draftsman on household electrical appliances and farm power and lighting outfits. Preferably with some practical shop experience. Salary $30. to $35. per week. Write W. E. B. Room 2502, 110 West 40th St., New York City.

V-503. Tool Designer with about five years experience in punch and die, jig and fixture work. Salary $30. to $40. per week. Write W. E. B., Room 2502, 110 West 40th St., New York City.

V-504. Designer of mechanical-electrical-apparatus, who is thoroughly familiar with design of small intricate mechanisms and their manufacture on a large scale. Must be technically trained and have had responsible design experience. Salary from $2,000. to $3,000. per annum. Organization is long established and is expanding its normal activities after a period of war work. To receive consideration a full chronological statement of experience and training is required. Write W. E. B., Room 2502, 110 West 40th St., New York City.

V-505. Capable and experienced armature winder thoroughly competent to take charge of repair department in an established electrical contracting and supply house in Western Pennsylvania.

V-506. Company in New York City manufacturing electrical appliances has vacancy in its engineering department for young man, technical graduate, capable of making tests upon and aiding in development of new apparatus.

V-507. College located on Pacific Coast, expecting expansion, wishes to add a high grade man who can soon qualify as a Professor of Electrical Engineering. Give record in detail, salary desired, etc.

V-508. Electrical Sales Engineer wanted as partner to establish business, and agencies, for new electrical devices with promising future. Requires some investment. State full particulars and if willing to work on West Coast.

V-509. Wanted Sales Engineer. Elevator safety field in New York and vicinity. Man must have wide acquaintanceship among architects and engineers in the building construction and equipment field. Man requiring breaking-in not acceptable. Strong personality; 28 to 38 years old. Salary and commission basis.

V-510. Engineer, preferably British, with long experience of heavy electric traction control, wanted to take full charge of designing and drafting departments for this class of work, in large English manufacturing concern. Give full details of design and manufacturing experience, technical and practical training and date services are available. Salary £500 to £650 according to qualifications.

V-511. Instructor wanted by technical school in Brooklyn for electrical laboratory and class-room work. Duties will include responsibility for an elementary electrical course, and assistance in a more advanced course. Must be an engineering school graduate and have had a few years practical experience. Previous teaching experience desirable but not absolutely necessary. Beginning salary $1500. to $1800. per year, depending upon individual. Apply by letter stating age, religious affiliation, education and experience, and enclose recent photograph if available.

SERVICES AVAILABLE

1238. College graduate in electrical and mechanical engineering, thirty-one years of age, Associate Member of

A. I. E. E. (Machinist by trade four years), three years Westinghouse test and service, three years sales engineer large oil company. Available on three weeks' notice to present employer.

1239. Electrical Engineer; graduate E. E., Associate A. I. E. E., age 27, single; four years shop and repair electrical work; two years testing; two years construction and engineering; experience with mining and mill electrical work. At present engineering office in U. S. N. Available upon application; references former employers; willing to go anywhere.

1240. Graduate electrical engineers (32) desires position with large concern charge of maintenance department. Several years experience in armature winding, dynamo, motor and welder repair and mechanical design. Considerable testing experience A. C. and D. C. machines. Will be released from U. S. N. R. F. by May 1.

1241. Electrical Engineer, age 34, discharged from service. Associate A. I. E. E. Ten years' experience with all kinds of electrical construction, operation and repairs. Formerly with Westinghouse. Understand steam and refrigeration, also machine shop experience. Desire executive position with industrial concern or power company. Will go anywhere.

1242. Electrical Engineer, with about fifteen years practical and executive experience along electrical and mechanical lines, such as motors, generators, watthour meters, transformers and testing, also street railways, wishes position as master mechanic, chief electrician, or charge of meter department or other electrical department. Located in South. Prefer small city. Married, age 34. Best references; $180. per month to start.

1243. Technical graduate, age 27, single, healthy, two years General Electric test, one year construction foreman, one year second lieutenant signal corps. Desires position as works electrical engineer or connection with industrial engineering firm. Salary $2500.

1244. Electrical and mechanical engineer, eight years' experience responsible charge of construction and operating work, with sales experience electrical apparatus, also twenty-two months experience in Engineers, U. S. Army; also graduate of technical college. Desires position. (Salary expected not less than $2000.)

1245. Position as manager or superintendent, twenty years experience as manager and engineer of hydroelectric company; has managed and designed hydroelectric and steam plants; can give best of references.

1246. Major, Statistics Branch, General Staff, U. S. Army, electrical and mechanical engineer, experienced in construction and operation of electric railways, engineering and military statistics, valuation of railroads. Prefer position as electrical engineer with railroad, but would consider any position for which qualified. Minimum salary $4000.

1247. An electric cable engineer thoroughly familiar with the design and manufacture of every commercial type of cable in use, backed by eight years executive experience in some of the largest cable companies. Have had considerable experience in solving problems in connection with industrial engineering and cost accounting. Willing to tackle anything. Minimum salary $3000.

1248. Teaching position desired by practical and theoretical electrical engineer. Graduate M. I. T. One year research and teaching under Dr. Kennelly; three years engineering and research with large and prominent telegraph and telephone companies. Unusually broad fund of information; available in Fall. Desire for more pleasant residential city cause for considering another position. Married.

1249. Electrical construction or maintenance foreman, practical experience of more than ten years, industrial electrical expert, known as A-1 man. Technical graduate. References of the best. Salary $2500. per year.

1250. Mechanical, electrical engineer, soon to be released from the Army. Have had eleven years' practical experience in the manufacture of electrical apparatus. Special experience in handling of labor. Technical graduate, thirty-four years of age.

1251. Executive mechanical and electrical engineer, age 35, married, technical graduate, member A. S. M. E., Associate A. I. E. E., desires position requiring tact and executive ability. Experienced in construction, operation and maintenance of stokers, boilers, hydraulic equipment, air compressors, electric generation, transmission, industrial lighting, heating, ventilation and refrigeration. Specialist in power production. Would take charge of power proposition for large industrial concern. Eastern location desired.

1252. Electrical graduate, Associate A. I. E. E., age 27, three years' experience in electrical testing department of large communication company, desires position as signal engineer with railroad or signal manufacturing company, or in testing department of power company. References furnished. Salary $2000.

1253. Graduate electrical and mechanical engineer, several years' experience on installation, building and repair work, wishes to locate in South America with company operating or planning operations in that territory. Age 23, available July 1.

1254. Electrical and mechanical engineer, graduate of M. I. T. Lieutenant in Naval Reserve Force. Available for position requiring engineering and business ability. Married, age 35, eight years' experience consulting mechanical and electrical engineer, two years general manager traction company, two years production engineer for large company. Highest references. No objection to foreign service. Salary commensurate with position, minimum in U. S. $5,000.

1255. Electrical Engineer, university graduate (1913), honorably discharged from U. S. Army. Age 28, Single. G. E. testing experience, electrical construction, maintenance and operation of power equipment and machinery around coal mines. Salary desired $225.-$275. per month. Available immediately.

1256. Technical graduate, single, age 22. Nine months with central station organization in meter work, inspector of services. One year with consulting engineering company on industrial light and power installations. Desires a permanent position with opportunity for advancement. New England preferred; other location considered. Salary $1300.

1257. Assistant Manager or Executive Engineer. Graduate electrical and mechanical engineer, age 30. Experienced in power plant and substation construction, operation and maintenance; organization; appraisal engineering; steel-mill operation and machine shop practice. Recently Lieutenant U. S. N., engineer officer in the battleship fleet. Desires permanent connection with opportunity for advancement. Salary $3600. to $4000., New York or Eastern location preferred.

1258. Class of 1919. Graduate electrical engineer from recognized technical college, is seeking a position with a firm that appreciates hard work, honesty, ability, and where men are advanced on their merits only. Have some experience in general engineering lines. Am foreign born and would develop into an excellent foreign representative. Available June 1.

1259. Executive engineer desires engagement with industrial, public utility or banking corporation. Industrial investigations, engineering, organization, management, public utility appraisals, railway engineering, construction, operation, transmission lines. Valuable to any manufacturer in determining best production and organization methods or to a banker in making reports and acting as advisor to his clients. E. E., age 40. Salary $6000.

1260. Electrical and mechanical engineer desires position as chief of design and development, with a concern manufacturing electrical apparatus. Thirteen years shop, laboratory and designing experience; two years departmental management. Familiar with measuring instruments, wireless apparatus and small machines. Foreign and domestic training. Age 30. Salary $3500.

1261. Junior electrical engineer and draftsman. M. I. T. graduate, age 26, single. One year experience in design and layout of substation equipment and active electrical construction work. Desires position offering broad opportunity.

1262. Electrical engineer or chief electrician in industrial plant. Age 35, married, technical education. Eighteen years broad electrical and mechanical experience in laying out, installation and maintenance of industrial lighting, motors, generators, etc. Ability to organize and handle men.

1263. Graduate (1915) of evening electrical engineering course, Associate A. I. E. E., recently released engineer officer U. S. N. R. F. Ten years' experience on the manufacturing, testing, inspection and installation of electrical and mechanical apparatus. Desires position on manufacturing, installation or tests. Single, age 27. Immediately available. Excellent references regarding ability, fitness and character.

1264. Experienced electrical mechanical engineer; college graduate; at present Engineer Officer, Naval Reserve, desires position, if sufficiently attractive, in Central American countries, Cuba, or Porto Rico. Thirty years old; married; both speak Spanish. Services available after two weeks notice.

1265. Electrical and mechanical engineer, age 34, desires position as electrical or maintenance engineer of industrial plant, preferably in the East. Ten years' experience with design and construction of power plants, distribution, lighting systems, and industrial motor application. At present engaged as electrical engineer of industrial plant.

1266. Graduate electrical engineer, age 35, married, eleven years' practical experience. Three years G. E. test and engineering department; three years central station operation and distribution; two years industrial installation and maintenance; three years power plant and substation design and construction foreman. References as to ability and character.

1267. Radio Engineer desires position as experimenter, research engineer, or instructor in radio theory at technical school. Technical graduate, electrical officer U. S. Navy. Married. Age 27.

1268. Available at once. What have you to offer electrical engineer, 30 years of age, and married? Past two years as testing and inspecting engineer motors, generators and mechanical equipment; six years practical experience in substation and powerhouse construction. Maintenance position desired.

1269. Completing work as U. S. Government electrical engineer on large port terminal. College graduate with fourteen years' experience in electrical power station installation and design, including high voltage transmission. Some knowledge of steam end of central station work and sales. Available about June 1. Salary $3000.

1270. Electrical engineer, ten years construction, operation and maintenance. Last thirteen months U. S. Army Engineer, France and Germany. Associate A. I. E. E. Age 27. Desires position with large manufacturing or power company. Minimum salary $2400.

1271. Telephone traffic engineer, age, 38, fifteen years' experience. Thoroughly familiar with Bell practices. At present General Traffic Superintendent. Salary $5000.

1272. Superintendent of electrical construction with twelve years' experience in switchboards, substations, underground cables, high and low tension work and general wiring of light and power. Have just completed one of the largest jobs in U. S. Desires position with good construction company. Age 36, married. Can furnish the best of reference.

1273. Executive, graduate engineer, 34, traveled extensively, well informed on big engineering projects. Now completing an investigation on proposed large public works. Available on short notice; vicinity of N. Y. C. preferred. Minimum salary $5000.

1274. Electrical Engineer desires position in construction department of large organization. Five years apprenticeship machine and erection shop. Four years with British War Mission, Inspection Department, steel and mechanical testing, electric wire and cable equipment. Unmarried, 27 years old. Salary about $125. per month. Best of references.

1275. Former Captain United States Army, technical graduate in electrical engineering with several years' experience in operating and commercial work with Public Service light and power corporation. Two years military service as personnel officer supervising selection of men and organization of the Army. Position desired as employment supervisor or commercial and sales engineer.

ACCESSIONS TO THE ENGINEERING SOCIETIES LIBRARY

(From March 1st to March 31st, 1919)

Unless otherwise specified, books in this list have been presented by the publishers. The Library does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

AERONAUTICAL ENGINES:

A critical Survey of Current Practice with Special Reference to the Balancing of Inertia Forces.

By Francis John Kean, 2nd edition. New York, Spon & Chamberlain; Lond., E. & F. N. Spon, Ltd., 1918, 101 pp., 49 illus., 31 pl., 8x5 in. cloth, $2.50.

CONTENTS: The Nature of the Problems, Classification of Aeroplane Engines, Relative Advantages of Different Types of Aeroplane Engines, Choosing the Number of Cylinders, Balancing the Sliding Parts of the Engine, Carburation, Ignition, Typical Aeroplane Engines, and Appendix.

This book consists of a course of ten lectures given during 1915 to men of the Royal Naval Air Service and the Royal Flying Corps, designers and engineering students.

COMPRESSED AIR PLANT.

By Robert Peele. 3rd edition. N. Y. John Wiley & Sons, Inc., Lond., Chapman & Hall, Ltd., 1919. 485 pp., 246 illus. 54 tab., 9 x 6 in., cloth, $4.25.

This edition has undergone a thorough revising and a number of chapters have been rewritten and several have been expanded, while old material has been condensed or omitted. The volume describes current practice in the construction and operation of compressors and discusses the applications of compressed air drilling, pumping and hauling, with special reference to mine service.

COTTON FACTS (Edition of Oct. 1918).

Compilation from Official and Reliable Sources of the Crops, Receipts, Exports, Stocks, Home and Foreign Consumption, Visible Supply, Prices, and Acreage of Cotton in the United States and other countries for a series of years, also Cotton Mill Statistics of the United States, Europe, India, etc., the Reports of condition of growing cotton crops, issued by the U. S. Department of Agriculture, and the Cotton Acreage and Yield of each State and County in the South according to the U. S. Census. Edited by Carl Geller. N. Y. Shepperson Publishing Co., 1918. 240 pp., 1 por., 7 x 4 in., cloth, $1.00.

This volume is the forty-third annual issue. In a book of pocket size, it presents the statistics needed by cotton merchants, manufacturers and growers, as indicated in the title.

THE DESIGN AND CONSTRUCTION OF DAMS.

Including Masonry, Earth, Rock-fill Timber and Steel Structures, also the Principal Types of Movable Dams. By Edward Wegmann. 6th edition, revised and enlarged. 1918 reprint revised. N. Y., John Wiley & Sons, Inc., 1918, 529 pp., 198 illus., 157 pl., 24 tab. 12 x 9 in., cloth $6.00.

The present volume is a reprint, with revisions, of the sixth (1911) of this well-known and popular treatise. A special feature of the book is the detailed information given concerning important dams in all parts of the world.

GASOLINE AND KEROSENE CARBURETORS. Construction—Installation—Adjustment.

A simple, comprehensive Treatise for practical Men, explaining all Principles pertaining to Carburetors for all Types of Internal Combustion Engines intended to operate on Liquid Fuels such as Gasoline, Kerosene, Bensol and Alcohol. By Victor W. Pagè. New York, The Norman W. Henley Publishing Co., 1919. 219 pp., 89 illus., 8 x 5 in., cloth, $1.50.

A handbook for operators of internal combustion engines. Explains in non-technical language the principles of carburetors, the usual modern types and the method of adjusting and repairing them.

HANDBOOK OF CHEMISTRY AND PHYSICS.

Compiled by Charles D. Hodgman, assisted by Melville F. Coolbaugh and Cornelius E. Senseman. Cleveland, Ohio, The Chemical Rubber Co., 1918. 557 pp., 7 x 4 in., flexible cloth, $2.50.

This compilation is intended to present in one volume of convenient size a comparatively comprehensive reference book for the use of chemists and physicists. The seventh edition has been enlarged by one hundred pages, which contain a revision of a table of the physical constants of organic compounds. This table now includes about two thousand substances. Various minor additions and corrections have been made throughout the work.

HEATON'S ANNUAL.

15th year, 1919. Published by Heaton's Agency, Toronto, Canada. 512 pp., (including advertisements) 7 x 5 in., cloth, $1.50.

A handbook of condensed commercial and industrial information on Canada. Describes the natural and commercial resources of the provinces, and industrial opportunities in the towns and cities. Much general information of use to visitors and business men is included.

A MANUAL OF CHEMICAL NOMOGRAPHY:

NOMEN. A Calculating Chart.

By Horace G. Deming. Champaign, Illinois, The University Press, 1918. In 2 parts, text and tables. $1.25. (Gift of Miles & Parris).

The Nomon is a nomographic reckoner, devised by the author, for the graphic solution of various arithmetical problems. Multiplication, division, powers, roots and logarithms can be treated by the eighteen charts, with an average error of one part in four or five thousand.

The Manual describes the method of using the Nomon and gives specific examples of its application to the solution of chemical problems, and indicates the kinds of calculations in which it is most useful.

MODEL MAKING:

Including Workshop Practice, Design and Construction of Models. A Practical Treatise for the Amateur and Professional Mechanic—giving Instructions on the Various Processes and Operations Involved in Model Making and the Actual Construction of numerous Models, including Steam Engines, Speed Boats, Guns, Locomotives, Cranes, etc. Lathe Work, Pattern Work, Electroplating, Soft and Hard Soldering, Grinding, Drilling, etc. are also included. Edited by Raymond Francis Yates. N. Y., The Norman W. Henley Publishing Co., 1919. 390 pp., 303 illus., 1 pl., 9 x 6 in., cloth, $3.

The author hopes that his book will promote interest in model engineering in this country and will also give a correct impression of its value as a recreation.

NINETEENTH YEAR BOOK:

Of The Rubber Association of America, Inc. N. Y., 1918. 119 pp., 9 x 6 in., paper.

Contains list of members, constitution and annual report for 1918.

PUBLIC UTILITY RATE FIXING:

Comments on Current Problems Pertaining to Public Utilities and to Rate Fixing. By C. E. Grunsky. San Francisco, Technical Publishing Company, 1918. 169 pp., 5 charts, 2 pl., 9 x 6 in., cloth, $2.50.

A reprint of a number of articles originally contributed to the *Journal of Electricity*, written in the hope that they may prove helpful in determining fair rates for the output of public utilities and in prescribing methods of procedure when rates are to be fixed; and that they may assist in the solution of some of the economic problems, which arise in the readjustment to peace conditions.

RADIATION, LIGHT AND ILLUMINATION:

By Charles Proteus Steinmetz. Compiled and edited by Joseph LeRoy Hayden. 3rd edition, N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1918. 305 pp., 127 illus., 1 pl., 14 tab., 9x6in., cloth, $3.00.

A series of twelve experimental lectures, most of which were delivered in 1908-9, with the exception of two lectures on Light Flux and Distribution, and Light Intensity and Illumination, the treatment is non-mathematical, and discusses the subjects in plain language.

This edition is apparently a reprint of the preceding ones.

THE SHIPBUILDING INDUSTRY:

By Roy Wilmarth Kelly and Frederick J. Allen, with an Introduction by Charles M. Schwab. Boston & N. Y., Houghton Mifflin Company, 1918. 303 pp., 64 pl., 8 x 6 in., cloth, $3.00.

The primary purpose of this volume, as stated by the authors is to describe and interpret for the general public, as well as for those employed in the shipyards, our war emergency shipping programme and the task of the shipbuilders. It is also hoped that the book will help those who wish to prepare themselves for executive positions and those considering shipbuilding or naval architecture as a possible life calling.

STEAM ENGINE TROUBLES:

A Practical Treatise for the Engineer, telling how to locate and remedy troubles with a Steam Engine. Cylinders, Valves, Pistons, Frames, Pillow Blocks and other Bearings, Connecting Rods, Wristplates, Dashpots, Reach-rods, Valve Gears, Governors, Piping, Throttle and Emergency Valves, Safety Stops, Flywheels, Oilers, etc., are all treated. By H. Hamkens. N. Y., The Norman W. Henley Publishing Co., 1919. 284 pp., 276 illus., 8 x 5 in., cloth, $2.50.

A simple account of the troubles which may arise in steam engine operation, the causes and the proper remedies, intended for the power plant engineer. Based on a series of articles published in *Power*.

STRUCTURAL ENGINEERS' HANDBOOK:

Data for the Design and Construction of Steel Bridges and Buildings. By Milo S. Ketchum. 2nd edition, N. Y. & Lond., McGraw-Hill Book Co., Inc., 1918. 896 pp., 165 tab., 9 x 6 in., flexible cloth, $5.00.

In preparing the new edition of this working manual for engineers, draftsmen and students, the author has added details of steel windows and doors, data on cement and gypsum tile roofs, solutions for bending moments in mill building columns and stresses in stiff frames, has rewritten and enlarged the chapter on steel highway bridges, and has corrected all known errors.

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PROCEEDINGS

OF THE

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Vol. XXXVIII
Number 6

JUNE, 1919

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TABLE OF CONTENTS

Section I.—Institute Affairs

A. I. E. E. 35th Annual Convention at Lake Placid........ 203
Pacific Coast Convention........ 205
Annual Convention of A. I. E. E........ 205
Spring Meeting of A. S. M. E........ 205
June Meeting of Institute of Radio Engineers........ 206
Annual Meeting of Society for the Promotion of Engineering Education........ 206
National Conference on Commercial and Engineering Training........ 206
Fifth National Exposition of Chemical Industries........ 206
A. I. E. E. Annual Meeting........ 206
Weaver Memorial Tablet........ 207
Edison Medal Presentation........ 207
A. I. E. E. Directors Meeting, New York, May 16, 1919........ 210
Report of Committee of Tellers on Election of Officers........ 212
Engineering Standards Conferences in France and England........ 212
The American Engineering Standards Association........ 213
Scientific and Technical Employees of the Government in Washington Organized........ 214
John Fritz Medal Presentation........ 214
The Engineering Societies to Assist the Joint Employment Service of Federal, State and Civic Bodies........ 215
Past Section Meetings........ 216
Past Branch Meetings........ 218
Engineering Service Bulletin........ 219
Engineering Societies Library........ 223
Associates Elected May 16, 1919........ 225
Associates Reelected May 16, 1919........ 231
Members Elected May 16, 1919........ 231
Transferred to the Grade of Member, May 16, 1919........ 231
Recommended for Transfer........ 231
Applications for Election........ 232
Studends Enrolled May 16, 1919........ 234
Personal........ 235
Obituary........ 237
Addresses Wanted........ 237

Section II.—Papers and Reports

Transmission Line Relay Protection. By H. R. Woodrow, D. W. Roper, O. C. Traver and P. MacGahan, Lake Placid Club, N. Y., June 24, 1919........ 631
High-Tension Single-Conductor Cable for Polyphase Systems. By W. S. Clark and G. B. Shanklin, Lake Placid Club, N. Y., June 24, 1919........ 663
The Effect of Transient Voltages on Dielectrics II. By F. W. Peek, Jr., Lake Placid Club, N. Y., June 27, 1919........ 717
Grounding the Neutral of Generating and Transmission Systems. By H. R. Woodrow, Lake Placid Club, N. Y., June 24, 1919........ 745
Problems of 220-kv. Power Transmission. By A. E. Silver, Lake Placid Club, N. Y., June 27, 1919........ 751
The Dielectric Field in an Electric Power Cable. By R. W. Atkinson, Lake Placid Club, N. Y., June 27, 1919........ 815
Report of Board of Directors........ 857

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VIEWS FROM LAKE PLACID CLUB

Tahawus (Marcy) Avalanch and McIntyre, from Hilcrest

View on 18-hole Golf Course Showing Part of Short Course

SOME OF THE 22 TENNIS COURTS NEAR FOREST CLUBHOUSE

WEST AUSABLE RIVER AND WILMINGTON ROAD

American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXVIII JUNE, 1919 Number 6

35TH A. I. E. E. ANNUAL CONVENTION AT LAKE PLACID

The 35th Annual Convention of the American Institute of Electrical Engineers will be held at the Lake Placid Club, Essex County, New York, June 24-27, 1919.

The selection of the Lake Placid Club as the Convention meeting place this year is a most happy one as it insures unsurpassed opportunities for recreation and entertainment. Situated in the heart of the Adirondacks, the natural attractions of the region make it an ideal place for all kinds of outdoor life; and in addition, the excellent equipment of the Lake Placid Club provides opportunities for practically all kinds of indoor and outdoor sports and recreations.

The technical program has been somewhat curtailed in order to leave ample time for the consideration and discussion of Institute policies at conferences under the auspices of the Committee on Development. Numerous modifications of the Institute's activities are being suggested, which demand the attention and study of the entire membership. Every member who can attend and take part in this important convention will find the experience both profitable and enjoyable.

Convention Sessions

The Convention will be opened by the presentation of the Annual Presidential Address, by President C. A. Adams, followed by the introduction of President-elect Calvert Townley. The remainder of the session will be devoted to the presentation of three papers under the auspices of the Protective Devices Committee.

Tuesday evening will be devoted to an informal reception and dance.

On Wednesday morning a session will be held at which the Reports of the Technical Committees for 1919 will be presented and discussed. These reports cover the activities of the various committees for the past year and the advances in the state of the art in the fields covered by the committees. At luncheon on Wednesday there will be a conference of the Committee on Development, Section Delegates and Institute Officers.

Thursday morning's session will consist of an open conference under the auspices of the Committee on Development including Section Delegates and Institute officers, to which all interested members of the Institute are invited.

On Friday morning there will be a technical session under the auspices of the Transmission and Distribution Committee at which four papers will be presented.

It will be noted that no specific program has been scheduled for the afternoons and two evenings during the convention. It is believed that the conferences under the auspices of the Development Committee on Institute policies will occupy some of the unassigned periods, and the Convention Committee this year, taking advantage of the special facilities of the Lake Placid Club is arranging an unusually complete schedule of contests, games and other entertainments which will occupy all of the spare time available.

A schedule of entertainment features will be announced at the convention.

A meeting of the Board of Directors and various committee meetings will be held during the Convention, notices of which will be sent to all concerned.

PROGRAM OF TECHNICAL PAPERS

Tuesday Morning, June 24

1. *President's Address*, by C. A. Adams.
2. *Present Day Practise of Transmission and Tie Line Relay Protection*, by H. R. Woodrow, D. W. Roper, O. C. Traver, and P. MacGahan.
3. *Grounding the Neutral of Generating and Transmission Systems*, by H. R. Woodrow.
4. *Grounded Neutral*, by Wm. E. Richards.

Wednesday Morning, June 25

5. *Reports of Technical Committees.*

Friday Morning, June 27.

6. *High-Tension Single-Conductor Cables for Polyphase Systems*, by W. F. Clark and G. B. Shanklin.
7. *The Dielectric Field in Electric Power Cables*, by R. W. Atkinson.
8. *Commercial Problems of 220-Kv. Power Transmission*, by A. E. Silver.
9. *The Effect of Transient Voltages on Dielectrics—II*, by F. W. Peek, Jr.

Transportation

Members are advised to consult their local ticket agents relative to train schedules and fares to and from Lake Placid (R. R. Station) and particular emphasis is placed upon the necessity for engaging Parlor Car and Sleeping

	Except Sunday	Daily	
	51	55	
Lve. New York (N. Y. C.)	8.30 a. m.	7.10 p. m.	No. 51.—Empire State Express (Adk. Div. No. 3) Parlor and Dining Cars to Utica.
Lve. Albany	11.35 a. m.	11.00 p. m.	
Lve. Utica	1.30 p. m.	1.25 a. m.	No. 55.—Western Express (Adk. Div. No. 5.) Sleeping Cars N. Y. to Lake Placid.
Ar. Lake Placid	7.10 p. m.	7.25 a. m.	
	....	49	
Lve. Boston (B. & A.)	....	4.45 p. m.	No. 49.—Parlor cars to Albany. Passengers from Boston and other points in New England connect with sleeping car from New York at Albany, leaving that point at 11 p. m. for Lake Placid direct.
Ar. Albany	....	10.40 p. m.	
Lve. Albany (N. Y. C.)	....	11.00 p. m.	
Ar. Lake Placid	....	7.25 a. m.	
	....	30	
Lve. Buffalo (N. Y. C.)	....	8.00 p. m.	No. 30.—Sleeping cars, Buffalo to Lake Clear Junction. Change at that point to local train for Lake Placid.
Lve. Rochester	....	9.40 p. m.	
Lve. Syracuse	....	11.35 p. m.	
Lve. Utica	....	1.25 a. m.	
Ar. Lake Clear Junction	....	6.08 a. m.	Passengers from points north and west of Buffalo should make arrangements to take No. 30 at Buffalo.
Ar. Lake Placid	....	7.25 a. m.	

Car accommodations at the earliest convenient date, as correspondence with the U. S. Railroad Administration indicates that only limited service will be available. From information received the following schedule showing the best trains from New York, Boston and Buffalo has been compiled. Members from other points should arrange to connect with these trains.

Fares

To Lake Placid from	One way	Round trip
New York.........	$12.29	$22.13
Albany............	7.69	13.85
Boston............	13.54	24.39
Buffalo............	11.15	20.07
Cleveland..........	17.17	30.80
Chicago...........	26.63	50.63
Detroit............	20.13	36.40
St. Louis..........	32.39	60.54

These fares include War Tax.

Sleeper and Parlor Car charges are additional.

Transportation from Lake Placid station to the Club will be provided by Club omnibuses.

Rates at Lake Placid Club

Single rooms per day		Double rooms per day		Meals
Without bath	With bath	Without bath	With bath	Day per person
$1.10 and 2.20	$3.30 to 5.50	$4.40 and 5.50	$6.60 to 11.00	$3.85

Reservation of Accomodations

Accommodations at the Lake Placid Club should be reserved as early as possible, by writing or telegraphing directly to the Club. Note particularly that there is a telegraph and post office at the club and all communications should be addressed to: Lake Placid Club, Essex Co., New York.

An automobile road map with a schedule of routes to the Lake Placid Club has been published with a separate announcement of the convention already mailed to the membership of the Institute.

PACIFIC COAST CONVENTION

The Pacific Coast Convention of the Institute will be held September 18—20, 1919 under the auspices of the Los Angeles Section. The local Convention Committee will be as follows: Carl E. Johnson, chairman; Julian Adams, vice-chairman; J. E. Macdonald and J. H. Cunningham. Convention Finance Committee, E. R. Northmore, H. A. Barre and R. H. Manahan; San Francisco representative, Robert Sibley; Spokane representative, John B. Fisken.

ANNUAL CONVENTION OF A. S. C. E.

The Forty-Ninth Annual Convention of the American Society of Civil Engineers will be held at St. Paul and Minneapolis, Minn., June 17–20th, 1919. Society headquarters at Radisson Hotel. The first day of the convention will be occupied by the Opening Meeting, Business Meeting and a Reception. The last three days will be devoted to trips to points of engineering interest, including the Duluth and Missabe Range Iron Mines, and also to various features of entertainment.

SPRING MEETING OF A. S. M. E.

The Spring Meeting of the American Society of Mechanical Engineers will be held at the Hotel Statler, Detroit, June 16 to 19, 1919. Papers will be presented on the following topics: Industrial Research; Conditions Necessary for Industrial Peace; Oil Engines; Fuels. Entertainment features are also scheduled.

JUNE MEETING OF INSTITUTE OF RADIO ENGINEERS

The next meeting of The Institute of Radio Engineers will be held on Wednesday Evening, June 4th, 8:15 p. m., in the Auditorium of the Engineering Societies Building, 29 West 39th Street, New York.

A paper on "Naval Aircraft Radio" will be presented by Mr. T. Johnson, Jr., Expert Radio Aid of the Navy. This paper will cover recent remarkable radiophone developments for Naval aircraft and will be profusely illustrated. Institute members are cordially invited to attend.

ANNUAL MEETING OF SOCIETY FOR THE PROMOTION OF ENGINEERING EDUCATION,

The 27th Annual Meeting of the Society for the Promotion of Engineering Education will be held at the Johns Hopkins University, Baltimore, Md., June 25-28, 1919 inclusive. Many questions connected with men in government service are to be discussed as well as questions of policy which must be settled before the exact relation of engineering schools to the R. O. T. C. can be determined.

NATIONAL CONFERENCE ON COMMERCIAL AND ENGINEERING TRAINING

A call has been issued by the Commissioner of Education for a national public conference on business training for engineers and engineering training for students of business. This conference will be held in Washington on June 23rd and 24th, 1919 and will be fully representative of all interests; educational institutions, commercial organizations and educational and engineering societies will be given an opportunity to express their views.

The conference has been called on behalf of the Conference Committee on Commercial Engineering, composed of administrative professors in engineering and commerce from educational institutions and representatives from the A. S. C. E., A. I. M. M. E., A. S. M. E., A. I. E. E., and a Committee of Fifteen on Educational Preparation for Foreign Service.

The following major topics will be discussed: Business training for the engineer; Engineering training for commercial enterprises; Significance of the war experience for engineering education; Training of the engineer for foreign projects.

FIFTH NATIONAL EXPOSITION OF CHEMICAL INDUSTRIES

The Fifth Annual National Exposition of Chemical Industries will be held this year in Chicago at the Coliseum and First Regiment Armory during the week of September 22nd. In connection with the Exposition a program is in preparation which includes meetings of the American Electrochemical Society, the American Institute of Mining Engineers, the American Ceramic Society and others.

ANNUAL MEETING

The Annual Meeting of the A. I. E. E. was held at Institute headquarters, 33 West 39th St., New York on Friday evening May 16, 1919 at 8:30 p. m. The meeting was called to order by Vice-President W. B. Jackson who in a few preliminary remarks called attention to remarkable progress of the Institute during the past year as outlined in the Annual Report of the Board of Directors distributed at the meeting. He then presented the report of the Committee of Tellers and announced the following as duly elected officers and managers: President, Calvert Townley, New York, N. Y., Vice-Presidents, C. E. Skinner, Pittsburgh, Pa., John B. Fiskin, Spokane, Wash., N. A. Carle, Newark, N. J., L. R. Jorgensen, San Francisco, Cal., Wills Maclachlan, Toronto, Ont., A. M. Shoen, Atlanta, Ga.;

Managers, L. E. Imlay, Niagara Falls, N. Y., L. F. Morehouse, New York, N. Y., F. F. Fowle, Chicago, Ill., Treasurer, Geo. A. Hamilton, Elizabeth, N. J.

Vice-President Jackson then called upon President-elect Townley who expressed his appreciation of the honor conferred upon him and the conviction that the problem confronting engineers today is one of finding ever increasing means and spheres of service to profession, State and Nation and of proveing the Institute's right to be considered one of the permanent National bodies.

The business meeting was then followed by the unveiling of the Weaver Tablet and the presentation of the Edison Medal both of which ceremonies are described elsewhere in this issue.

WEAVER MEMORIAL TABLET

The ceremony of the presentation and unveiling of the Weaver Memorial Tablet directly followed the Annual Business Meeting of the Institute, May 16, 1919. This tablet was presented to the Institute, by a group of members, in commemoration of the services of William D. Weaver, now retired and residing at Charlottesville, Va.

Vice-President Jackson called upon Dr. A E. Kennelly to say a few words in appreciation of the work of Wm. D. Weaver and he spoke in part as follows:

"I have the high honor to present to you this evening the evidence of our consideration and regard for one of our honored members, William Dixon Weaver, Lieutenant in the American Navy, and also Volunteer Chief Engineer of the American Navy during the Spanish-American War.

He was on the first Greely Relief Expedition in 1883. He founded the *American Electrician*. He was an editor of the *Electrical World* from 1893 to 1905, and he established a very high record for electrical journalism in this country at the time when Mr. Martin and he were joint editors of the *Electrical World*.

How he was able to ferret out and discover electrical books, electrical writings and electrical writers, always passes my own comprehension. . . . Everyone who knew him will, I am sure, agree with me in the remarkable qualities that he possessed as a judge and a selector and an inciter and a stimulator of American engineering literature.

He took very active part in the organization and development of the International Electrical Congress of 1904 in St. Louis. . . . . If he had done nothing else but that, he would have been worthy of the highest praise.

He was also led by his great love of books and of literature to strive for a great library here of electrical literature, and he took a very prominent part with others in the establishment of our own great Engineering Library.

We owe this presentation in large measure to the work of past Vice President, B. A. Behrend. We are all proud of Mr. Weaver tonight, but proud of Mr. Behrend in having accomplished this result.

This man whom I have the honor to extol is an American author, an American engineer, an American journalist, and a patriot, and a sailor last but not least.

I have the honor to present to you this very fine bronze portrait of him, and I hope that for generations to come it will be found in this building as representing the lineaments of a man who always thought of others and served others, because he understood them.

EDISON MEDAL PRESENTATION

The ceremonies in connection with the presentation of the Edison Medal to Benjamin G. Lamme, "for invention and development of electrical machinery," took place at the Annual Meeting of the Institute, May 16, 1919 directly following the business meeting and Weaver Memorial Tablet presentation.

Vice-President Wm. B. Jackson called upon Dr. Carl Hering who gave an outline of the founding and meaning of the Edison Medal and a summary of the accomplishments of the various recipients.

The Chairman then called upon Mr. B. A. Behrend who gave a history of the accomplishments of Mr. Lamme. He spoke in part as follows:

In Clark County, Southern Ohio, between Dayton and Springfield, about two score and ten years ago Benjamin Garver Lamme was born. The life on that farm gave him the rugged constitution without which even his great talents would not have carried him through. . . . . . . The early morning hours in 1887 and 1888, we are told, were often spent in poring over the pages of Sylvanus P. Thompson's "Dynamo Electric Machinery." Ohio State University . . . . was Mr. Lamme's Alma Mater. After working on the flow of air and gas in pipes for the professor of geology, he boldly applied for a position to Mr. Westinghouse, who had then just organized the Philadelphia Company. . . . . . . After a few months, his employer, Mr. A. T. Gillespie, recommends him to the Electric Company, where we find him in 1889 in the testing department under Mr. Albert Schmid. . . . . . .

Soon he becomes foreman of the testing department, and within a year his mind begins to turn to inventions. From 1889, in increasing numbers from year to year, he applied for patents, at the rate of ten a year in 1898, and up to the present time reaching the surprising total of 153. . . . . . .

That he was early in this field is indicated by the fact that nearly all the patents taken out on rotary converters in those days were in his name. . . . .

When it comes to 60-cycle converters, he stood practically alone for many years, and his work has been instrumental in giving these machines the final high position which they now hold in the industry. . . . . .

Again, he can claim to have been the leader in the direct current railway motor development, as far as fixing types of apparatus is concerned. . . . .

In this work on rotary converters, railway motors, and D. C. generators, it can surely be said that he has had much to do with solving the problem of commutation, in the sense of determining the conditions which affect commutation and taking advantage of those characteristics and features which improve commutating conditions. . . . .

In the induction motor field, while he was not among the first to develop induction motors, yet his work began in the latter part of 1892, and he was the first to produce commercial motors for the Westinghouse Company, and was among the first in America. . . . . .

There are many other fields in which he has had a hand, but not as prominent as the above. In the single phase railway system, which he creates, he deserves much credit for the fact that he successfully commutated alternating currents, after it had been pretty definitely accepted as being one of the impracticable or impossible things. . . .

With the advent of the steam turbine, Mr. Lamme turned his universal genius to the development of a type of turbo-alternator known as the "parallel-slot" type. . . . . . .

Two years ago, when the Secretary of the United States Navy established the Naval Consulting Board, the Directors of the Am. Inst. of Electrical Engineers were requested to nominate, and to recommend to the Secretary of the Navy, two members of their great body. . . . . . . It was a great pleasure for the present speaker that he then had an opportunity to commend Mr. Lamme's name. The good work done by Mr. Lamme on the Naval Consulting Board in his capacity as Chairman of the Inventions Committee is yet too early to appraise.

In accepting the medal Mr. Lamme gave an address in part as follows:

My appreciation of the honor conferred on me in the award of the Edison Medal cannot readily be expressed. Looking back upon my earliest days in the electrical field, when the forces with which I was allied were in bitter rivalry with those, at the head of which was the man whose name this Medal bears, it is hard to conceive what a tremendous change has taken place in so few years. . . . . . . Now the rivalries in electrical industry are between organizations, the members of which may be the best of friends.

Most people are particularly interested in accounts of wonderful inventions or discoveries; and the cold-blooded methods of the engineer in driving through all obstacles to a desired result do not contain for them any especial elements of romance or excitement. They do not recognize that the work of the engineer carries responsibilities, which ofttimes is not the case with the inventor; moreover, they are not aware that the engineer in the manufacturing field, when he once embarks on a program, is obliged to see it through to the end, and that he must stand or fall by his results. To state it very briefly, the experimental attracts more attention than the analytical. The modern engineer, especially in the electrical field is largely an analytical man and his adventures in analysis do not appeal to the popular taste. . . . . . .

In an industrial organization, the engineering developments are almost always the result of co-operation of many trained minds, and in consequence, it is difficult to give any one man a large share of the credit. The work of such organization more resembles that of an army than of an individual. . . . . . . Many of the developments now being carried through in the engineering field so far exceed any individual capabilities, that only the united efforts of many brilliant minds can attain success; and he who does his part, can well take pride in the greater accomplishment, even if there may be less personal glory in it. . . . . . .

Without the backing of immense resources in capital, equipment, and experience, and without the greatest co-operation of many analytical minds, there could have been no such an accomplishment as the modern high speed, huge capacity turbo generator sets. . . . . . .

As another illustration, in the railway field the steam locomotive has been a long development, requiring the experience of years. . . . . . .

I will tell the story of one development, in which I have always had pride, which, however, is but little known because of lack of spectacular elements. This concerns the single-reduction-gear railway motor development, back in the Summer of 1890, just a little over a year after I entered the electrical business, and before the company with which I am connected had any organized Engineering Department.

Leading up to this, a little personal history is required. On May 1st, 1889, by an accidental circumstance, I was enabled to enter the employ of the Westinghouse Company at Pittsburgh, where I was placed in the test room by Mr. Albert Schmid, then Shop Superintendent. My college training had covered a purely Mechanical Engineering course, but I was more or less interested in electrical machinery from the construction standpoint. Some months after I had entered the company, Mr. Schmid spoke to me very pleasantly one evening in the test room, and a little later I received a message to call at his office the next morning. There, he said he had been told that I had had practice at "figuring things." I said that I had done some calculating on the flow of natural gases in long pipe lines for the State Geologist of Ohio, but had never figured on anything electrical. He said that made no difference as long as I could figure, and he wanted to try me on something. He then explained that he believed electrical machinery could be calculated. . . . . . . He wanted to try me out. I agreed, of course, to make the attempt and he then showed me a little pamphlet, written by an Englishman, in which there were certain crude methods of calculation worked out. He reviewed this very painstakingly with me and then asked me what I thought. I told him that I would like to try my hand at such calculation and so I was set to work on it using my spare time between tests, to see what I could do in the way of checking up the saturation curves on our existing alternating current machines. I soon found that I could get reasonably close approximations, in so far as our magnetic and electric data at that time would permit. . . . . . . This was really the beginning of the calculation of electrical machinery in the Westinghouse Company.

In the latter part of 1889, Mr. Westinghouse was planning to go into the railway equipment business and he asked Mr. Schmid to have a study made of the subject. Mr. Schmid then told me to get busy and first investigate the existing systems and then see what I could do toward *calculating* a suitable railway motor. In January, 1890, I prepared specifications, from calculations, for a double-reduction railway motor very much along the general lines of the then existing types. This was the first machine which the Westinghouse Company produced entirely from calculations, and when built, it was sufficiently close to the specifications to be put on the market as a commercial machine. This was known as the No. 1 Westinghouse double-reduction motor. I am telling this because it leads up to the development of the single-reduction-gear motor.

In August, 1890, during a strike at the company's plant, the test room was shut down completely, and to keep busy I took up the problem of the electrical design of a single-reduction-gear motor for railway work. . . . .

Right at the start, my rough figures indicated that such a machine should be of a 4-pole type in order to keep down the weight. With this as a starting point, I naturally turned toward the Westinghouse alternator type of field

construction with its internal, symmetrically spaced, poles. This appealed to me as presenting several great advantages for a railway motor construction, for the external yoke of the machine naturally formed an ironclad protection for the motor as a whole, and it would be a very easy matter to "house" the lower half to protect it against damage from below. So far, so good,—but when it came to the armature, I was fairly "stumped" for awhile. I first worked out a surface wound armature, such as was common practise on railway motors at that time, but found at once that, due to the large iron-to-iron gap, the construction was practically prohibitive with four poles. This apparently brought me up against a blank wall. However, various other possibilities were then considered, among them the "slotted" type of armature, such as was being used on small capacity machines by the United States Company, then a subsidiary of the Westinghouse. . . . . To my great pleasure, the first figures indicated that, from the magnetic standpoint, the slotted construction allowed a quite low speed motor of proportions permissible for a street car equipment. However, when it was attempted to work out the armature winding itself, another most serious difficulty appeared. Up to this time, the one type of winding considered practicable for four-pole machines was what is now known as the "parallel" type, with four circuits, and requiring four brush arms unless all the commutator bars were cross connected. This appeared to me to be impracticable for railway work, and we were faced by a most serious difficulty. . . . . . .
After two or three days' work, I found a winding which gave exactly what was desired and this was used in the construction of the first motors of the new type.

I then proposed machine wound coils, insulated before being put on the core. . . . . . . The foreman of our transformer winding department and myself, both of us with no previous experience as armature winders, then put the machine wound coils on these two slotted armatures, both of which stood the shop tests and both were sent out on the first car equipment. Even at that time, I considered this a most conclusive proof of the superiority of machine wound coils, in that two inexperienced men could make a success of this winding in their first attempts.

In the latter part of 1890, these two machines were put on test and checked quite closely with the calculations, and what was more important, the slotted armatures commutated better than we expected and the new type of armature proved to be thoroughly satisfactory.

. . . . . .

This single-reduction-gear motor should be looked upon as the direct "ancestor" of the modern universally adopted type of railway motor. . . .

So much for development,—now as to inventions; in my case, they could mostly be classed as *by-products*, as someone has aptly put it. In an engineering and manufacturing organization, the first efforts of the engineers are expended in obtaining certain desirable results in the most successful manner. Usually, if a result is one not accomplished before, or is an improvement over existing practice, then new and novel, and consequently patentable, ideas quite frequently are involved. The real engineer on this work usually does not set out to "invent something."

. . . . . .

From the standpoint of development and inventions, the past looms large, but how about the present and the future? In looking over the past history of electrical engineering, the engineer may be inclined to think that the golden age of development and invention is past, and that the future contains no corresponding promise of new and startling things. But I do not agree that this is so. The pioneering period may be over, but the true development age has possibly just begun. The work is growing more difficult year by year, as our accumulation of knowledge grows. We are working ahead of our data, just as we did twenty to thirty years ago. . . . . . .

A. I. E. E. DIRECTORS' MEETING, NEW YORK, MAY 16, 1919

The regular monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Friday, May 16, 1919, at 2:30 p. m.

There were present: Vice-Presidents W. B. Jackson, Pittsfield, Mass., and John B. Taylor, Schenectady, N. Y.; Managers C. E. Skinner, Wilfred Sykes, and F. D. Newbury, Pittsburgh, Pa., N. A. Carle, Newark, N. J., Charle S. Ruffner, St. Louis Mo. E. H. Martindale, Cleveland, O., Walter A. Hall, Lynn, Mass., W. A. Del Mar and W. I. Slichter, New York, G. Faccioli, Pittsfield, Mass.; Treasurer George A. Hamilton, Elizabeth, N. J.; Secretary F. L. Hutchinson, New York.

In the absence of President Adams, who is in Europe, Senior Vice-President Jackson presided.

The action of the Finance Committee in approving monthly bills amounting to $10,668.28, was ratified.

A request for an additional appropriation from each Founder Society for the continuation of the work of the Engineering Societies Employment Bureau through the present calenda year, was presented; and upon the recommendation of the Secretary and the Chairman of the Finance Committee, a resolution was adopted that the Board, concurring in the view that the present service of the Engineering Societies Employment Bureau should be continued, as a war activity, during the year 1919, with particular reference to the members of the Founder Societies and other technical men who are or have been in the service of the Army or Navy, authorizes the necessary appropriation.

The Meetings and Papers Committee recommended that the regular meeting for October be held under the auspices of the Electrophysics Committee in combination with the American Physical Society, in Philadelphia, at the usual time; that a joint meeting be held in New York, also in October, under the auspices of the Telegraphy and Telephony Committee and the Institute of Radio Engineers; that a meeting be held in New York in November under the auspices of the Power Stations Committee.

In accordance with the recommendation of the Board of Examiners, the following action was taken upon pending applications: 127 Students were ordered enrolled; 177 applicants were elected to the grade of Associate; 3 applicants were re-elected to the grade of Associate; 7 applicants were elected to the grade of Member; 4 applicants were transferred to the grade of Member.

The Annual Report of the Board of Directors for the fiscal year ending April 30, 1919, as prepared by the Secretary, was presented, approved and ordered presented at the Annual Business Meeting of the Institute to be held on the evening of May 16. (The Report appears elsewhere in this issue).

The Annual Report of the Treasurer for the fiscal year ending April 30, 1919, which agreed with the annual report of the auditors as embodied in the Board of Directors' report, was presented, accepted, and ordered filed.

Annual Reports of various standing committees were presented. These reports, which had been included in full or abstracted in the Board of Directors' report, were received and ordered filed for the use of incoming committees.

In accordance with Sec. 37 of the Constitution, the Board considered the appointment of a Secretary for the administrative year commencing August 1, 1919; and Secretary F. L. Hutchinson was reappointed.

A report from Mr. C. E. Skinner, Institute delegate to the Chicago Conference on Department of Public Works, under the auspices of the National Service Committee of Engineering Council, April 23-25, was presented, and accepted with an expression of appreciation of Mr. Skinner's service .

A report from the Standards Committee was presented, embodying a request for an extension of time of sixty days from May 16 for the completion of the year's work of the Committee, in order to finish the general revision of form of the Standardization Rules which had been undertaken; and submitting for the approval of the Board, a statement of the amendments and additions to the Standardization Rules which had been adopted by the Committee during the year. The Board granted the Committee's request for an extension of time and approved the proposed amendments and additions to the Rules.

In addition to the above, many other matters relating to important activities and the general policy of the Institute were discussed and in most cases were referred to various committees and officers for further consideration. Reference to these matters may be found in this and future issues of the PROCEEDINGS under suitable headings.

REPORT OF COMMITTEE OF TELLERS ON ELECTION OF OFFICERS

To the President,
American Institute of Electrical Engineers.

DEAR SIR:—This committee has carefully canvassed the ballots cast for officers for the year 1919–1920. The result is as follows:

Total number of ballot envelopes received		2486
Rejected on account of bearing no identifying name on outer envelope, according to Art. VI., Sec. 34, of the Constitution	33	
Rejected on account of voter being in arrears for dues on May 1, 1919, as provided in the Constitution and By-laws	60	
Rejected on account of ballot not being enclosed in inner envelope, or on account of inner envelope bearing an identifying name, according to Art. VI, Sec. 34, of the Constitution	63	
Rejected on account of having reached the Secretary's office after May 1, according to Art. VI, Sec. 34, of the Constitution	4	
Rejected on account of improper marking of ballot	43	
Blank ballots	14	217
Leaving as valid ballots		2269

These 2269 valid ballots were counted and the result is shown as follows:

For President	
Calvert Townley, New York	2201
Scattering and blank	68
For Vice-Presidents	
C. E. Skinner, Pittsburg	2182
John B. Fisken, Spokane	2169
N. A. Carle, Newark	2139
L. R. Jorgensen, San Francisco	2122
Wills Maclachlan, Toronto	2074
A. M. Schoen, Atlanta	1887
J. B. Whitehead, Baltimore	762
Blank	279
For Managers	
L. E. Imlay, Niagara Falls	2227
L. F. Morehouse, New York	2217
F. F. Fowle, Chicago	2210
Blank	153
For Treasurer	
George A. Hamilton, Elizabeth, N. J.	2231
Blank	38

Respectfully submitted,
HENRY C. CLEMENT, *Chairman*
IRVING W. EDWARDS,
CHAS. W. LEE,
P. C. PAQUETTE,
JAMES GOLDSBOROUGH,
Committee of Tellers.

ENGINEERING STANDARDIZATION CONFERENCES IN FRANCE AND ENGLAND

Professor Comfort A. Adams, President of the Institute, and Mr. H. M. Hobart sailed for Europe April 18, 1919, to attend conferences in France and England on engineering standardization.

At Paris they were to be joined by Dr. C. O. Mailloux, and these three, as a delegation representing the U. S. National Committee of the International Electrotechnical Commission, were to attend a meeting of the Special Committee on Rating of the I. E. C., at Paris, May 5 to 7, 1919. This Committee includes representatives from Belgium, France, Great Britain, Italy, Sweden, Switzerland, and the United States.

It is believed that the Conventions of the I. E. C., which have been interrupted during the past four years by the war, will now be resumed.

Later the delegation planned to attend, as representatives of the American Engineering Standards Committee, a conference of the British Engineering Standards Association, in London, on Anglo-American cooperation in engineering standards, and to return to the United States about the middle of June.

THE AMERICAN ENGINEERING STANDARDS ASSOCIATION

Engineering standards are the forerunners of trade, as upon these standards are based the specifications which accompany inquiries for engineering materials and equipment. Many societies of high standing in the United States have issued standards which compare favorably with those issued by most authoritative European societies but they have not been available to foreign engineers due to the latter not being acquainted with the relative standing of the societies issuing them.

We now have the prospect of seeing an authoritative series of American standards bearing the stamp of approval of an organization which will have a recognized international standing, due to its affiliations with the great national engineering societies and government departments.

The American Engineering Standards Committee, at a meeting held May 17, approved a proposed revised constitution under which the Committee will be reorganized as "The American Engineering Standards Association." Under this new constitution the Association will assume its regular functions as soon as the parent societies, including the American Institute of Electrical Engineers, have voted their approval.

According to this constitution the purposes of the Association will be as follows:

1. To unify and simplify the methods of arriving at engineering standards, to secure co-operation between various organizations and to prevent duplication of work;

2. To promulgate rules for the development and approval of standards;

3. To receive and pass upon recommendations for standards submitted, as provided in the Rules of Procedure, but not to initiate, define, or develop the details of any particular standard;

4. To act as a means of intercommunication between the organizations and individuals interested in problems of standardization;

5. To co-operate with similar organizations in other countries and to promote international standardization;

6. To give an international status to approved American engineering standards.

7. To give an internationally recognizable standing to American Engineering Standards.

The Association will be composed of not more than three representatives from each of the principal engineering societies, government departments, and other organizations interested in the formulation of standards each such representative having one vote.

The affairs of the Association will be managed by a Board of Directors, which will consist of twelve members. This Board will have power to deal with all affairs of the Association, except the approval of standards.

The Association will pass upon engineering standards and classify them as "Recommended Practise," "Tentative Standards" or "Standard," the advance of status to "Standard" requiring an affirmative vote of ninety per cent of the association.

Each organization appointing representatives of the Association will pay annual dues of five hundred dollars for each representative and other funds may be obtained in any manner approved by the Association.

The constitution, which appears to have finally met with the informal approval of the participating organizations, is the result of many months of hard work in reconciling the divergent views of the individual founders. The members of the Association are to be congratulated on the successful completion of their labors. It s the patriotic duty of every American to lend his earnest support to the American Engineering Standards Association to the end that American Engineering Standards may receive the world-wide recognition, which is their due.

SCIENTIFIC AND TECHNICAL EMPLOYEES OF THE GOVERNMENT IN WASHINGTON ORGANIZED

The first steps toward permanent organization or unionization of technical and scientific men was taken recently when on May 8, 1919 the scientific and technical employees of Government departments and agencies in Washington, D. C., got together at a mass meeting. The subject of organization had previously been widely discussed but was finally brought to a head by the action of the Joint Congressional Reclassification Commission in stating that they wished to deal with employees only through organizations.

The principal advantages to be derived from such an organization were pointed out by Rodney H. True, Dept. of Agriculture, the Acting Chairman, as follows: Improvement of conditions and facilities for more effective scientific and technical work; Adequate presentation of the needs and results of such work to the public and to legislative and administrative officers; Greater freedom in both official and non-official activities; Just and reasonable salaries based on service performed and economic and social conditions which prevail; Greater public recognition of the aims and purposes of research; Advancement of service and technology as an essential element of national life.

Three plans of organization were offered, covering the fundamental principles government employees could utilize. The first was based on the plan adopted* in England and would have permitted the organization to operate only through existing scientific organizations.

Dr. Humphreys proposed the second plan under which an independent organization of federal employees engaged in scientific and technical work would be created. The objection to highly technical men becoming affiliated with unions was covered in detail.

The plan finally adopted by the conference was sponsored by Dr. Rosa, chief physicist of the Bureau of Standards. He pointed out the unfavorable conditions under which government scientists solving big problems are compelled to work and the certainty that the present service will become inefficient from loss of personnel due to insufficient compensation.

The following resolutions were adopted:

1. A scientific and technical branch of Federal Employees' Union No. 2, coordinate with the departmental branches. One could be a member of a departmental branch only, or of the scientific branch only, or *of both branches*. Double membership would *not* involve double dues.

2. It is suggested that, pending the completion of a permanent organization, the meeting proceed to a temporary organization comprising a chairman, secretary, and a general interim committee having executive powers.

3. The general committee to consist of the chairman, the secretary, and representatives from the bureaus, one for each 20 members or major fraction thereof. All bureaus of a department to elect representatives in common when desired.

4. It is suggested that the representatives of the several bureaus be elected at special meetings of local members (including new members) of the department of bureau branches to be held at the call of the central organization of the Federal Employees Union No. 2, not later than Monday, May 12, the general committee so constituted to meet at the call of the chairman.

5. The funds required to initiate work will be available at once from the union organization. The present annual dues of the Federal Employees Union are $4.00 (35c. per mo.). The admission fee is $1.00. Should the new branch decide to undertake extensive special work, a small addition to the dues might be necessary.

JOHN FRITZ MEDAL PRESENTATION

On the evening of May 22, 1919 at 8.30 p. m., the John Fritz Medal was presented to General George W. Goethals in the auditorium of the Engineering Societies Building, 33 West 39th St., New York.

The Board of Award formed of sixteen men, four representatives from each of the four National Societies of Civil, Mining, Mechanical and Electrical Engineers awarded the Medal to General Goethals for achievement as builder of the Panama Canal. He is the fifteenth recipient. This medal represents the highest honor which can be paid by the engineering profession of America.

Mr. Chas. F. Rand, Past President of the American Institute of Mining and Metallurgical Engineers presided. Addresses were delivered by W. L. Saunders, Past President, A. I. M. M. E., Hon. Henry L. Stimson, Ex-Secretary of War, Ambrose Swasey, Past President, A. S. M. E., and response by General Goethals.

THE ENGINEERING SOCIETIES TO ASSIST THE JOINT EMPLOYMENT SERVICE OF FEDERAL, STATE, AND CIVIC BODIES

During the war the Four National Societies of Civil, Mining, Mechanical and Electrical Engineers, under the auspices of the American Engineering Service Committee of Engineering Council rendered valuable aid to the Government, placing many technical men in the Army, Navy and industries of the country at a time when they were greatly needed. With the signing of the armistice the need for Government service naturally ended, but the greater problem of returning to civil employment the discharged soldier and sailor at once presented itself, and is daily becoming graver and more urgent. To meet this situation the Engineering Societies Employment Bureau of Engineering Council was organized with the Secretaries of the Societies of Civil, Mechanical, Mining and Electrical Engineers as Directors.

At the invitation of Colonel Arthur Woods, Special Assistant to the Secretary of War, the Engineering Societies have been requested to bring to the attention of all their members the availability of not only the professional men who are returning but also the supply of miners, mechanics and other skilled labor among the enlisted men and to emphasize that the Army discipline has not only made these men quicker thinkers but also more willing and obedient workers—that the whole result has been conducive to the regular habits and clean living, steadying these men and fitting them to quicker meet emergencies, and has instilled more loyalty to their superiors and to their jobs.

Further, the military instruction which they have received has increased the men's powers of concentration. The War Department believes the employers of skilled labor cannot be too strongly impressed with the fact that the employment of discharged soldiers will be advantageous to the employer and economically beneficial to the country.

The following is a list of the vocations of the men who are now returning:

Auto Mechanic
Blacksmith
Boilermaker
Bricklayer
Carpenter
Air, or Gas Compressor Operator
Concrete or Cement Worker
Construction Foreman or Supt.
Crane Operator
Draftsman
Electrician
Engineer
Engineman and Fireman
Foundryman
Gasoline Engineman or Repairman
Gas Plant Worker
Hydraulic Press Operator
Instrument Maker
Laborer (Classified)
Lineman and Cableman
Machinist and Mechanic
Metal Finisher
Millwright
Miner or Quarry Worker
Painter
Pipefitter

Photographer
Plasterer
Railroad Operating Man
Refrigeration Operator
Rigger and Cordage Worker
Sheet Metal Worker
Structural Steel Worker
Telegraph and Wireless Man
Transportation Man
Water Supply Man
Welder and Cutter.

To this end every member of the Institute is requested to take up the matter actively and to write to the Secretary or to Mr. W. V. Brown, Manager of the Engineering Societies Employment Bureau at 29 West 39th Street, New York, detailed opportunities for placing men in any of the industries in which they are acquainted.

PAST SECTION MEETINGS

Boston.—April 22, 1919, Engineers Club. Paper: "The Present Status of the Industrial Lighting Codes" by George H. Stickney. Joint meeting with New England Section of Illuminating Engineers. Attendance 35.

April 28, 1919, Engineers Club. Subject: Committee on Development of A. I. E. E. Discussion of points being considered by the Committee on Development.

May 6, 1919, Engineers Club. Paper: "Utilizing the Time Characteristics of Alternating Current" by Henry E. Warren. Paper was illustrated by exhibits and lantern slides. Election of officers as follows—chairman, I. E. Moultrop; vice-chairman, W. I. Middleton; secretary-treasurer, Ira Cushing. Attendance 65.

Chicago.—April 28, 1919, Western Society of Engineers Rooms. Paper: "Wireless Telephony and Telegraphy in War," by A. A. Oswald. Joint meeting with Electrical Section of Western Society of Engineers. Attendance 200.

Cleveland.—April 21, 1919, Hotel Statler. Subject: "Electricity vs. Air for Portable and Semi-Portable Tools." Speakers: E. L. Connell and B. W. Sweet. Capt. E. H. Martindale showed lantern slides of pictures taken by himself on the other side, and briefly explained same. Attendance 43

Denver.—April 19, 1919, Minnequa Club, Pueblo, Colorado. Paper: "History of Power Transmission," by Paul M. Lincoln. Automobile trip to Pueblo and inspection of steel plant of the Colorado Fuel and Iron Company. Attendance 105.

Detroit- Ann Arbor.—April 25, 1919, Detroit Board of Commerce. Paper: "Induction Motor Characteristics," by B. F. Bailey. Attendance 60.

May 1, 1919, Detroit Board of Commerce. Paper: "Wireless Telephony and Telegraphy in War," by A. A. Oswald. Joint meeting with Detroit Engineering Society. Attendance 200.

May 16, 1919, Detroit Board of Commerce. Subject: "The Influence of the War Upon Scientific and Engineering Developments in the United States." Speaker: Colonel R. A. Millikan.

Erie.—May 13, 1919, Board of Commerce Rooms. Subject: "Audible Electric Signaling in Industrial Plants, and Electro-Acoustic Engineering. Speaker: Prof. V. Karapetoff. Attendance 112.

Fort Wayne.—April 17, 1919. Subject: "An Engineering Discussion of Fractional Horsepower Motors." Speakers: E. B. George, Roy Young, E. A. Schaefer, and R. B. Roberts. Attendance 30.

Ithaca.—April 24, 1919, Franklin Hall, Cornell University. Subject: "Public Hearing on the Proposed Bill in the U. S. Senate to Change the Present English System of Weights and Measures to the Metric System in 1922. Brief speeches and remarks for and against the measure by Professors E.L. Nichols and A. E. Wells, and Messrs. H. Halperin, W. E. Voisinet, H. Caminez, K. Tennygold, H. Richards, Jr., and F. A. Halsey. Attendance 101.

Los Angeles.—March 25, 1919, Edison Hall. Illustrated address by Lieut. Ellery Stone, U. S. N., on "Radio Engineering." Attendance 30.

Lynn.—May 6, 1919, General Electric Hall. Illustrated lecture by Mr. C. E. Eveleth on "Submarine Detectors." Attendance 166.

Milwaukee.—April 16, 1919, Athletic Club. Illustrated address by Mr. George R. Lawrentz on "Aeroplane Construction." Attendance 410.

April 29, 1919, Athletic Club. Address by Mr. A. A. Oswald on "Wireless Telephony and Telegraphy." Address was illustrated with motion pictures, and a practical demonstration of radio telephony was given.

Minnesota.—April 15, 1919, Main Engineering Building, University of Minnesota. Paper: "The Street Railway Problem." by Horace Lowry. Attendance 100.

Panama.—March 30, 1919, Balboa Heights. Paper: "Testing of Hydraulic Turbines," by William T. O'Connell. Attendance 18.

Philadelphia.—April 14, 1919, Engineers Club. Discussion on points under consideration by Committee on Development. Addresses by Secretary F. L. Hutchinson, Dr. William McClellan and Mr. J. Franklin Stevens. Attendance 45.

Pittsburgh.—May 13, 1919, Chamber of Commerce. Paper: "Merchant Marine Electrical Auxiliaries," by W. E. Thau. Attendance 125.

Portland.—March 11, 1919. Address by Colonel Zinn of U. S. Engineers on "Work of the United States Engineers." Attendance 55.

April 7, 1919. Illustrated address by Mr. J. W. Sadler on "Concrete Ship Construction." Attendance 47.

Schenectady.—April 18, 1919, Edison Club Hall. Smoker was held in the Edison Club Hall. Refreshments were served followed by musical entertainment. Attendance 350.

April 23, 1919, Edison Club Hall. Discussion of points brought out by the Committee on Development. Attendance 95.

May 2, 1919, Edison Club Hall. Papers: (1) "Pliotron Vacuum Tubes and Their Application to Radio Apparatus," by W. C. White; (2) "Radio Apparatus for Aircraft and Ground Stations," by E. M. Kinney. Models of apparatus were exhibited and some demonstrations made.. Attendance 285.

Election of officers as follows—chairman, C. S. VanDyke; vice-chairman, C. M. Davis; J. L. Burnham and S. H. Blake; treasurer, H. P. Broderson; secretary, L. B. Bonnett.

Seattle.—March 29, 1919, Commercial Club. Address on "Power Transmission," by Mr. Paul M. Lincoln. Mr. John B. Fisken spoke on "The Engineer—His Composition, His Opportunities and His Duties." Attendance 60.

Spokane.—April 18, 1919, Chamber of Commerce. Paper: "City Transportation from an Engineer's Viewpoint," by T. E. Phipps. Joint meeting with A. S. C. E., A. I. M. E., and Spokane Engineering and Technical Association. Attendance 49.

St. Louis.—April 30, 1919, Engineers Club. Illustrated address by Mr. H. W. Eales on "Present Practise in Sub-Station Design." Discussion on points brought out by Committee on Development. Attendance 58.

Toronto.—April 25, 1919. Election of officers as follows—chairman, Ashton B. Cooper; secretary, Daniel M. Fraser; executive committee, L. B. Chubbuck, H. C. Don Carlos, F. R. Ewart, C. Sisson, W. Volkman, A. C. Johnston.

May 2, 1919. Engineers Club. Address by Professor Valdimir Karapetoff on "Fundamentals of the Magnetic Circuit." Attendance 65.

Washington.—May 13, 1919, Cosmos Club. Election of officers as follows—chairman, Milton M. Flanders; secretary, R. Karl Honaman; executive committee, J. E. Smith, Thos. McKavanaugh, Quinton Adams, R. J. Patterson, E. T. Walker. Motion pictures (1) "The King of the Rails," (2) "The Manufacture of Mazda Lamps," by courtesy of General Electric Company. Attendance 31.

PAST BRANCH MEETINGS

University of Arkansas.—May 14, 1919. Papers: (1) "Inventions of Nicola Tesla," by Ernest Hollabough; (2) "Transmission Lines" by J. C. Black; (3) "The Rogers Underground Wireless," by Chester Parker. Attendance 13.

Bucknell University.—April 14, 1919. East College. Address by Ensign L. H. Noll on 'The Advantages of Oil Over Coal a a Fuel." Attendance 18.

Carnegie Institute of Technology.—May 7, 1919. Papers (1) "Some Notes on Life in the Navy," by G. M. Porter; (2) "The Progress of the United States in Aeronautics," by H. L. Parker; (3) "The Use of the Radio in the War," by C. F. Sheakley. Attendance 24.

University of Cincinnati.—April 24, 1919, Engineering Building. Address by Lieut. Vernon Wiegand on "The Wireless Telephone Equipment on Airplanes." Attendance 40.

May 8, 1919, Engineering Building. Paper: "Shell Making at the American Rolling Mill," by A. A. Van Pel. Attendance 38.

Georgia School of Technology.—April 30, 1919, Y. M. C. A. Illustrated address by Prof. C. P. Eldred on "Iron and Steel Industries in the Birmingham District." Attendance 60.

May 8, 1919, Y. M. C. A. Paper: "Public Utilities," by Preston Arkwright. Attendance 85.

University of Maine.—April 23, 1919, Lord Hall. Addresses as follows—(1) "The Seniors' Inspection Trip," by Messrs. Farnum and Wade; (2) "New Western Union Office in Washington, D. C.," by Mr. Swicker; (3) "Summer Experiences with the Westinghouse Company," by Mr. Hopkins. Attendance 29.

Massachusetts Institute of Technology.—April 24, 1919. Address by Lieut. Colonel Pridgin on "The Signal Corps in France." Attendance 52.

April 29, 1919. Address by Sir Arthur Wright on "Commercial Aspects of Electrical Engineering." Attendance 62.

University of Michigan.—April 24, 1919, Engineering Building. Address by Mr. G. E. Lewis on "Hydroelectric Power Plants." Attendance 24.

University of Minnesota.—April 14, 1919, Engineering Auditorium. Lecture by Mr. L. T. Ferris on "Inductive Interference between Power and Telephone Lines." Attendance 28.

Ohio Northern University.—April 18, 1919, Dukes Memorial. Papers: (1) "International Gaps," by C. Nobrega; (2) "Oscillograph Demonstration," by F. F. Turner. Attendance 20.

May 1, 1919, Dukes Memorial. Addresses as follows—(1) "Manufacture of Transformers," by L. A. Trumble; (2) "Curves as Applied to Electrical Engineering," by Prof. F. W. Parsons.

Oregon Agricultural College.—May 15, 1919. Election of officers as follows—A. L. Manning, president; W. F. Lathrop, vice-president; Ray Avrit, secretary-treasurer. Attendance 14.

Pennsylvania State College.—May 5, 1919. Illustrated lecture by Prof. Stavely on "Spectacular Illumination at the Panama-Pacific Exposition." Attendance 43.

University of Pennsylvania.—April 30, 1919, Engineering Building. Election of officers as follows—chairman, W. H. J. McIntyre; vice-chairman, F. J. Haines; secretary, J. M. Ryan; treasurer, H. C. Fehr; asst. secretary, W. H. Whiting. Attendance 33.

University of Pittsburgh.—May 12, 1919. Address by Mr. H. Q. Chan on "The Methods of Testing Insulators on High-Tension Transmission Lines." Attendance 16.

Purdue University.—April 8, 1919, Electrical Building. Election of officers as follows—chairman, L. A. Malott; vice-chairman, G. W. Pilcher; secretary, T. K. Hartley; treasurer, A. R. Kaufman; executive board, R. A. Whitford; W. A. Clark, and E. A. Roth. Attendance 80.

May 6, 1919, Electrical Building. Address on "My Experience in a U. S.

Submarine," by R. A. Whitford. Attendance 40.

Throop College of Technology.—Address by Mr. C. O. Poole on "Some Special Problems of Hydroelectric Practise." Lecture illustrated by lantern slides. Attendance 200.

University of Washington.—April 8, 1919, Forestry Hall. Paper: "The Radio Field," by Dr. H. H. Lester. Attendance 17.

Washington State College.—April 11, 1919. Address on "What is Electricity" by Prof. B. L. Steel. Attendance 19.

ENGINEERING SERVICE BULLETIN

Opportunities.—The Institute, is particularly anxious to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in this BULLETIN. The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Services Available.—Under this heading brief announcements (not more than fifty words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office files.

Note.—Copy for publication in the BULLETIN should reach the Secretary's office not later than the 20th of the month if publication in the following issue is desired. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

Engineering Societies Employment Bureau.—This is a joint bureau under the auspices of the Engineering Council. The Institute's employment service is coordinated with that of the joint bureau.

OPPORTUNITIES FOR SERVICE

V-512. Salesman, age 30 to 40 years, personally acquainted with large jobbers and manufacturers of bicycles and bicycle accessories. To represent prominent accessory manufacturer. Must be alive to the importance of cycle industry, capable of meeting the big men and a good judge of human nature. State salary desired.

V-513. Young technical graduate preferably having test experience with manufacturing company or central station. State age, experience, references, and salary expected. Box 1095 E. E., Kansas City, Mo.

V-514. A large manufacturing firm in the Middle West would like to get in touch with young men who are just finishing university courses in electrical or mechanical engineering, or who left their university courses to enter Army or Navy service and are now looking for employment. Good opportunities will be open for the right men in sales, engineering, design and research work. In answer please state educational training and experience.

V-515. Wanted a high grade electrical engineering draftsman. Prefer man who has had at least seven to ten years practical experience, in which work he had to make own measurements in field for necessary alterations in wiring layouts, low-tension bus bar equipment, etc. Graduate of recognized school of electrical engineering. Man of type able to exercise good judgment in making small alterations to wiring layouts and location of electrical equipment. Location northern New York.

V-516. Wanted graduate in engineering who wishes to teach physics and mechanics in an engineering college. The salary would probably begin at about $1700. Location New York State.

V-517. Several opportunities for high grade men to connect with the marketing and exploitation of an electrical device for the publicity field. Men capable of promoting local companies. Those with facilities to influence capital will receive preference.

V-518. Wanted. Assistant professor, electrical engineering, by engineering college in Ohio. Must be graduate of an engineering college. Practical and teaching experience desired. Salary $2000. Apply giving education, experience, age, references and photograph.

V-519. Instructor in electrical engineering by Ohio engineering College. Technical graduate with practical experience, teaching experience desirable. Application should state education, experience, age, references, and enclose photograph. Salary $1500.

V-520. Dutch export house in New York wants an electrical engineer preferably Hollander and Delft graduate, with experience in the purchase of electrical and other machinery. Give experience, age and salary required.

V-521. Teacher. Assistant professor of electrical engineering in state institution in the middle Mississippi valley. $1700. to $1800. for nine months work.

V-522. Man with technical education in electrical engineering and some experience in telephone or telegraph work to teach those subjects in large educational institution. Location Pennsylvania. Salary $1500. to $1800.

SERVICES AVAILABLE

1276. Associate professor of electrical engineering wishes position in practice, during year's leave of absence from teaching, with possibility of permanence. Extensive research experience in high-voltage, radio, electrolysis and other problems. Nine years' experience teaching, four engineering practice. Good worker, executive, technical writer. Age 37, married, excellent health. Willing to travel or reside anywhere. Available August 1.

1277. Electrical engineer, teacher. Practical and educational experience includes successful administration of department in state university, specialized educational war service, charge of large construction for Government. Active, constructive, tactful. Now assistant professor in large university; seeks broader responsibility.

1278. Electrical engineer, university graduate, Member A. I. E. E., desires position as electrical engineer of an industrial plant. Seven years' experience in installation and operation in large manufacturing plants and mines. Age 32. Salary $3000.

1279. An assistant professor of electrical engineering in a large eastern university would like a position for the Summer months; wide practical experience; locality no object.

1280. Electrical engineer, Swede, 30 years old and married, wants position with power company offering good future prospects. Ten years' experience in a wide field of electrical engineering, especially hydro-electric development and transmission line design, construction and calculation.

1281. Electrical engineer, technical graduate, two years' experience operation and maintenance of power plants. Lieutenant Signal Corps. In charge of construction of two temporary wireless receiving and sending stations for instruction purposes. Experienced in motor installations, telephone installation, line construction, operation and maintenance. Desires position as distribution engineer or power superintendent, $2000.

1282. Technical graduate, Associate member A. I. E. E., wishes position with medium sized electrical industry or in power distribution. Have had experience on turbines, generators, motors, transformers, etc., also business experience. Have had two years G. E. test experience. Minimum salary $2500. Position preferred in eastern Massachusetts.

1283. Electrical engineer, university graduate, 12 years' experience in central station design, construction and operation, also commercial engineering (rates). Author of technical press articles, papers and books on central station subjects, collaborator of N. E. L. A. committees. Desires suitable position in central station or manufacturing concern. Best references.

1284. Engineer, age 36, university education, now in charge of department of a public utilities commission and fully experienced in financial, executive, accounting, operating, construction, appraisal and rate-fixing phases of electric, water, gas and railway utilities, desires connection with organization where this broad executive and technical ability may have unlimited scope. Monthly salary at start $300.

1285. Summer work in electrical or mechanical engineering desired by assistant professor with four years practical engineering. Especially experienced in power plant practice and automobile design. Available June 15. Age 29.

1286. Electrical and mechanical engineer, graduate, seven and one-half years practical experience from Westinghouse apprentice to assistant master-mechanic and engineer of equipment interurban electric railway (four and one-half years) manufacturing own rolling stock; one and one-half years foreman electrical construction; Army engineer one year. Associate A. I. E. E. Experienced in handling men. Age 31. Married. Desires position as electrical engineer or chief electrician. Salary $175.

1287. Mature engineering executive. Member A. I. E. E. Age 35, experienced developing intricate mechanical electrical apparatus for quantity production. Will act as assistant to head of smaller manufacturing corporation. Handle commercial, efficiency and reconstruction studies, selection of personnel and routine management during absence. Salary $5000. or less with gradual acquirement of interest.

1288. Electrical engineer desires position as designing engineer on A-C. and D-C. generating equipment. Technical graduate with thorough practical experience on this work with large manufacturing concerns. Served one and one-half years in France as Captain of Engineers. Excellent references.

1289. A young active electrical engineer in Spain, who for five years has been holding responsible positions in a large power concern at Barcelona and who is familiar with the customs of the country, wishes to represent concerns manufacturing electrical and mechanical apparatus, transformers, rotating machinery, measuring instruments, etc.

1290. Graduate electrical engineer, eight years general construction and maintenance, G. E. test, Associate A. I. E. E., Member Am. Electrochemical Society, 30 years, married, desires position as research engineer in electricity or electrochemistry. Has private electrochemical laboratory. Would consider maintenance foreman or instructorship in large public utilities company. Salary $3000. Month's notice required. Present work not congenial.

1291. Electrical engineer, B. S. degree, desires position as instructor or with consulting engineer. Two years with public service corporation, one year instructor, one year artillery electrician, U. S. A. Experienced in motor testing, telephones, searchlights, and gas engines. Associate member A. I. E. E., Member N. E. L. A. Age 25. Best references.

1292. Graduate electrical engineer desires position with large possibilities for future, preferably in production work. One year inventory and appraisal experience; six months power plant and distribution system design; eighteen months maintenance and illumination engineering; one year as engineer officer, U. S. Navy. Available approximately July 1.

1293. Wanted executive position, New York City. Over ten years in engineering and commercial lines, including export. Thirty-four years old, married; now officer in Army. Can obtain release.

1294. Teaching position desired by an M. M. E., 32 years of age. Three years practical and five years teaching experience. At present with one of the large universities.

1295. Graduate electrical engineer, 35, with 10 years' experience in construction, operation and testing with G. E. and other large companies. Wishes position in charge of construction and maintenance with a progressive concern.

1296. Electrical engineer, now Lieutenant U. S. Navy, expects to be released July 1, desires position as chief electrician or engineer of large industrial plant. Graduate of technical university, 2 years small meters, 2 years G. E. Co. trouble work, 3 years assistant chief electrician large industrial plant, 1½ years steam turbine operation and manufacture in U. S. Navy. Age 30. Salary expected $250. per month.

1297. Superintendent of construction, electrical engineering graduate, recently released Army Officer. Eleven years' experience on steam and hydroelectric plants, substations, transmission lines and distribution systems. Willing to go anywhere. Available on short notice. Salary $3000.

1298. Have you opening for man 34 years old with technical training and experience in operation and construction of electric power equipments? Especially strong on industrial plants, high and low-tension apparatus, switchboard operation and installation, high-tension transformer stations. Economical handler of labor and material, executive ability and energy. Location no object. Make offer.

1299. Graduate electrical engineer, Associate Member of A. I. E. E., age 31, six years' practical and four years' teaching experience desires to re-enter the practical field as electrical engineer or chief electrician in industrial plant. Westinghouse testing experience, electrical construction, steel mill maintenance and operation and substation operation. Minimum salary $185. per month.

1300. Superintendent of Power or chief electrician, age 30, married, 13 years' experience high-tension construction and maintenance, repair and application of electric power to industrial machinery. Released from Army, wants connection with construction or operating company, or large industrial company using electrical power. Minimum salary $1800.

1301. Graduate (1918) of five year course in electrical engineering desires position as instructor in engineering institute. One year experience with Westinghouse Electric & Mfg. Co. Acted as assistant to professor of mechanical drawing for one year. Tutored a class of fifty Freshmen for two years in elementary physics.

1302. Welding executive, nine years' practical experience. Formerly assistant head electric welding Emergency Fleet Corporation. Shipbuilding experience; conducted research and development all branches of electric spot and arc welding, also gas welding. Can handle men to paying advantage. At liberty after June 15. Age 30 years, married.

1303. Electrical engineer, university graduate, age 35, at present Lieutenant in U. S. Navy, desires position with shipbuilding or operating company. Over 8 years' experience in design and maintenance of direct-current motors and generators; 1½ years supervision of installation of complete electrical equipment on shipboard. Available on reasonable notice.

1304. Engineer, mechanical or electrical, 23 years of age, experienced in testing; one year's experience as design and development engineer of D-C. machines and nautical instruments. Prefer position as design and development engineer, but will consider any position for which qualified. Minimum salary $2000. per year. Available at once.

1305. Assistant manager or engineer, now assistant electrical engineer, public utility. Age 27. M. I. T. 1915. Honorable discharge Engineer Corps, U. S. A. Experience central station design, office records and data. Excellent personality, energetic, resourceful, initiative. Production man, not a salesman. Salary $2500.

1306. Technically trained electrical engineer, who has had three years' experience teaching and assisting in laying out courses in large eastern university. Past three years laboratory director for large gas and electric company. Experience includes electrolysis investigation and prevention; high voltage tests. Salary expected $2400. to $3000.

1307. Factory Executive, now employed as factory manager of a well known manufacturing firm in the Central States, desires position with progressive firm, manufacturing high grade machinery or electrical apparatus; broad experience in the design and manufacture of electrical and electrical-mechanical apparatus and factory supervision; wide-awake and energetic; maximum production guaranteed; highest credentials.

1308. Electrical engineer, 31, graduate of a European college in 1913. Experience in projecting construction and operation of electrical power plants and systems; has general knowledge of European practice; speaks several modern languages. Minimum salary $3600. Married.

1309. Electrical and mechanical engineer, 34, acting as consulting engineer to British Admiralty on questions of design, manufacture, inspection of naval ordnance stores, desires engagement in America or Canada as technical engineer, assistant to managing director, works manager, or chief draftsman. Held responsible appointments in England. Experienced in design, manufacture, test, erection dynamo electric machinery. Can handle labor efficiently. Salary $3500. to $4000.

1310. Manager. An assistant manager of electric property in city of 20,000 desires larger field. Age 34. Salary $3600. to $4000.

1311. Graduate mechanical electrical engineer, Toronto 1911, desires position with larger future than present location. Experienced in design and construction of steam electric power plants, heating, industrial plant engineering. At present employed in electro-chemical plant in charge of instruments and tests of electrical equipment, boilers, turbines, pumps, etc. Salary $3000.

1312. Electrical engineer, engaged in hydro-electric design, construction and operation in South America, will consider change to company where free hand is given. Technical training with fifteen years' experience in hydro-electric field. Available early next year. Might arrange to leave in three months. Salary $6000. in Latin America, Spain or the Phillippines, or in U. S. A. $4500.

1313. Electrical and mechanical engineer. Accustomed to positions demanding broad engineering knowledge and executive ability. Expert in power plant operation, construction and design. Thoroughly familiar with modern shipyard plants including construction, machinery, installation and maintenance, operation, etc. Graduate of Massachusetts of Technology. Services available immediately. No restrictions as to location. Present salary $4200.

1314. Captain, O. R. C., U. S. Army, wants executive position with electric light and power company. Graduate engineer, nine years' experience electrical and mechanical. Capable of getting new business and holding same. Best references. Minimum salary $3600. per year. Available immediately.

ENGINEERING SOCIETIES LIBRARY

The library, which comprises the individual libraries of the American Institute of Electrical Engineers, the American Society of Mechanical Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Civil Engineers, and the United Engineering Society, is 'ocated on the thirteenth and fourteenth floors of the Engineering Societies Building. In addition to engineering works it contains the general reference books of the allied sciences such as Physics, Mathematics and Chemistry. The library also contains publications of practically all the engineering societies in the world as well as current and pound sets of more than 1,000 engineering periodicals in English and other languages.

In order to place the facilities of this great engineering library at the disposal of persons residing out of town, a Library Service Bureau has been established, and a staff of expert searchers and translators is prepared to cover almost any engineering topic. Charges for service are at actual cost. Photostat copies of prints, drawings, etc., are $0.25 per 10 x 14 inch sheet.

All communications should be made as definite as possible so that the information received may be what is desired and not include collateral matter of no interest. The time spent in searching for such collateral matter will be saved, and information sent more promptly and in more usable shape.

Members who may desire it will be kept info med regarding current publications on any engineering subject.

The library is conducted as a f ee public library of reference. It is open to the public from 9 a. m. to 10 p. m. on all week days except holidays.

Accessions.—(April 1–April 30, 1919) Unless otherwise specified, books in this list have been presented by the publishers. The Institute does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

AEROPLANE CONSTRUCTION AND ASSEMBLY:

By J. T. King and N. W. Les ie. Minneapolis. Press of The William Hood Dunwoody Industrial Institute. 115 pp., 77 illus., 5 pl., 9 x 6 in., cloth, $1.50.

This work is intended as a practical manual for mechanics engaged in constructing and rigging airplanes and as a guide to instructors. Airplane assembly, construction and materials, and the theory of flight are discussed.

INDUSTRIAL GOODWILL:

By John R. Commons. N. Y. McGraw-Hill Co., Inc.; Lond., Hill publishing Co., Ltd., 1919. 213 pp., 3 charts, 8 x 6 in., cloth, $2.00.

CONTENTS: Commodity, Machinery, Goodwill, The Public, Democracy, Solidarity, Theory and Practice, Security, Labor Market, Insurance, Health, The Shop, Education, Loyalty, Personality, Depression, The World.

The author discusses the present day problems of labor and capital, and their relations to each

other, and the method of solving them, which have been practiced or proposed.

IRON AND STEEL:

(A Pocket Encyclopedia) Including Allied Industries and Sciences. By Hugh P. Tiemann. With an Introduction by Henry Marion Howe. 2nd edition. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1919. 514 pp., 7 x 4 in., flexible cloth, $4.00.

In a volume of pocket size, the author provides a combination of dictionary, encyclopedia and handbook of the iron and steel industries, intended for the metallurgist. The number of terms, and the text also, have been increased about one-half, the chief additions being more extended discussions of heat treatment, physical properties and testing, and of metallographic subjects.

THE MINERAL DEPOSITS OF SOUTH AMERICA:

By Benjamin L. Miller and Joseph T. Singewald. 1st edition. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1919. 598 pp., illus., maps, 9 x 6 in., cloth, $5.00.

An account of the economic geology of the countries of South America, based on an extended visit by the authors in 1915, and a study of the literature. It forms a digest of the available information on the mineral deposits of the continent. Selected bibliographies are appended to each chapter, and an adequate index is provided.

MINING PRACTICES:

Compiled from the Engineering and Mining Journal by the Editorial Staff. N. Y., McGraw-Hill Book Co., Inc., sole selling agents, 1919. 105 pp., 56 illus., 11 tables, 12 x 9 in., cloth, $1.50.

These articles have been selected to illustrate the range in conditions that must be met in mining operations and to indicate in both a general and a specific way how mining practices are developing.

OFFICE ADMINISTRATION:

By J. William Schulze 1st edition, 2nd impression. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1919. 295 pp., illus., folded cha t, 8 x 5 in., cloth, $3.00.

Written to present a thorough discussion of the principles and methods which underlie efficient and economical management, for use by executives and students of business. It embodies the author's added experience and observation and is intended to replace his earlier book, "The American Office."

OFFICE MANAGEMENT:

Its Principles and Practice cov ring Organization, Arrangement, and Operation with Special Consideration of the employment, Training, and Payment of Office Workers.

By Lee Galloway. 2nd printing. N. Y., The Ronald Press Co., 1919. 701 pp., 97 illus., 1 pl., 9 x 6 in., flexible leather. $6. (delivered).

This book is intended as an exposition of the basic principles of office administration in its widest sense, with adequate illustration by examples of successful practice.

PHYSICS AND CHEMISTRY OF MINE VENTILATION:

A Practical Handbook for vocational schools, and for those qualifying for mine foreman and mine inspector certificates.

By Joseph J. Walsh. 2nd edition. N. Y., D. Van Nostrand Co., 1918. 219 pp., illus., tables, 8 x 5 in., cloth, $2.

A textbook of theory and practice for students with limited mathematical knowledge. This edition has been thoroughly revised and a chapter on the sampling and analysis of mine gases has been added.

PRINCIPLES OF RADIOTELEGRAPHY:

Prepared in the Extension Division of the University of Wisconsin by Cyril M. Jansky. 1st edition. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd. 1919. (Engineering Education Series) 242 pp., 179 illus., 9 x 6 in., cloth, $2.00.

A textbook in which the use of mathematical expressions is used, while an attempt has been made to explain the principles involved so fully that a reader unable to follow the mathematical demonstrations may still acquire some understanding of the subject.

A considerable part of the book is devoted to a discussion of electromagnetic theory and apparatus in order that the student may acquire an intelligent idea of the principles of the operation of radiotelegraphic apparatus.

PUNCHES AND DIES:

Layout, Construction and Use. By Frank A. Stanley. 1st edition. N. Y. McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1919. 434 pp., 618 illus., 9 x 6 in., cloth, $4.00.

This book has been written to provide die-makers, tool-makers and tool draftsmen with certain definite information heretofore not available as a whole. Almost ninety per cent of the material, the author states, has not been published before.

Quantitative Analysis:

By Edward G. Mahin. 2nd edition. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1919. 605 pp., 122 illus., tables, 8 x 5 in., cloth $3.50.

The author has endeavored to produce a volume that would occupy a position between the complete reference work and the bare outline of laboratory exercises. It covers the material that he wishes to take up in his college courses, and at the same time presents a theoretical and practical discussion of the subject. In addition to the presentation of the general subject, a section on the analysis of industrial products and raw materials is included.

This edition has been carefully revised and partly rewritten, and new material has been added.

Sewage Disposal:

By Leonard P. Kinnicutt, C. E. A. Winslow, and R. Winthrop Pratt. 2nd edition rewritten. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1919. 547 pp., 141 illus., 136 tables, 9 x 6 in., cloth, $4.

This volume offers a general survey of the problem from the various viewpoints of the chemist, the sanitary biologist and the engineer, with particular reference to the conditions of American practice. The aim has been to discuss rather fully the fundamental principles of chemistry and bacteriology which are involved and to include the more important aspects of the engineering works designed to carry them into operation. This edition has been completely rewritten so as to bring in new data and recent viewpoints on all the topics treated. Several chapters have been much enlarged and several new ones have been added.

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Putnam, Kearney C., Chief Electrician, United States Navy, 280 Broadway, New York; res., 49 Hatfield Place, Port Richmond, S. I., N. Y.

Redsell, James, Construction Foreman, Toronto Hydro-Electric System, 23 Hallam St., Toronto, Ont.

Reich, Roland R., 1081 Lincoln St., Easton, Pa.

***Reid, Ernest A.**, Instructor in Electrical Engineering, Univ. of Illinois, Urbana, Ill.

Richards, Harold A., Asst. Engineer, Century Electric Co., 1827 Pine St., St. Louis, Mo.

Robinson, Wilber H., Electrician, Sunset Motor Co.; res., Marlboro Apt., Spokane, Wash.

Ross, Samuel William, First Class Draftsman, New York & Queens Elec. Light & Power Co., Long Island City; res., 1848 Monroe Ave., New York, N. Y.

Russell, Charles Herbert, Commercial Engineer, Westinghouse Electric & Mfg. Co.; res., 416 Franklin St., E. Pittsburgh, Pa.

Russell, R. J., Vice-Pres. & Secretary, Century Electric Co., 1827 Pine St., St. Louis, Mo.

Sakamoto, Tsuneki, Electrical Dept., Imperial Government Railways, Tokyo, Japan.

Sauerborn, Nicholas T., Electrician, American Can Company, 120 Broadway, New York; res., 402 S. Main St., Geneva, N. Y.

Schwartz, Ernest Lincoln, Instructor in Electrical Engineering, Georgia School of Technology, Atlanta, Ga.

Seelye, Howard P., Elec. Engr., Diatribution Engineer Dept., Detroit Edison Co., Detroit; res., 132 Glendale Ave., Highland Park, Mich.

Shubart, Benedict, Manufacturers Agent, 520 Boston Bldg., Denver, Colo.

Sidle, Walter P., Electrical Engineer, Westinghouse Elec. & Mfg. Co., New York; res., 151 Overpeck Ave., Ridgefield Park, N. J.

SISSON, CHARLES E., Engineer, Canadian General Electric Co., Peterboro, Ontario.

SMITH, ALFRED QUINTON, Engg. Asst., Executive Dept., American International Shipbuilding Corp., Hog Island, Pa.

SMITH, CHRISTOPHER I., Electrical Engineer, American Radio & Research Corp.; res., 203 Boston Ave., Medford Hillside, Mass.

STAFORD, RICHARD H., Local Manager, Hydro-Electric Power Comm., North Bay, Ontario.

STARK, FRANK, Operating Vice-President, Standard Electric & Elevator Co., Inc., Baltimore, Md.

STAUBITZ, LOUIS PIERCE, Testing Engineer, Commonwealth Edison Co.; res., 4701 Drake Ave., Chicago, Ill.

STEINEL, CONRAD J., Supt. of Telegraph, L. A. & S. L. R. R., 559 Pacific Electric Bldg., Los Angeles, Cal.

STEINER, HARRY A., In charge of Production Electrical Motors, Century Electric Co.; res., 5 So. Taylor Ave., St. Louis, Mo.

STEMLER, EDW. J., Chief Operator, 59th St. Power Station, Interborough Rapid Transit Co., 600 W. 59th St., New York, N. Y.

STEWART, THOMAS J., Manager, Baltimore Office, L. K. Comstock & Company, 1001 Lexington Bldg., Baltimore, Md.

STOLL, CHARLES JOSEPH, Chief Draftsman, Standard Electric & Elevator Co.; res., 1405 N. Central Ave., Baltimore, Md.

STREBIG, CHARLES F., Dist Sales Manager, Cooper Hewitt Elec. Co., 311 Drexel Bldg., Philadelphia, Pa.

STROUD, STANLEY, Salesman, Canadian Westinghouse Co., Toronto; res., 81 Dunsmure Ave., Hamilton, Ont.

SWISHER, CHARLES L., Prof. of Physics, State School of Mines; res., 1003 11th St., Rapid City, So. Dakota.

TAYLOR, WILLIAM HENRY, Elec. Supt., Western Australian Government Electricity, Supply & Tramways, Power House, East Perth, Western Australia.

TERADA, MASUHO, Electrical Dept., Mitsubishi Dockyard & Engine Works, Kobe, Japan.

TOURIANSKY, GREGORY I., Asst. Chief Draftsman, Elec. Section, American International Shipbuilding Corp., Hog Island; res., 23 N. Front St., Darby, Pa.

TOWLES, E. E. MAJOR, Signal Corps,, United States Army, Camp Meade' Md.: res., 612 E. Main St., Jefferson City, Mo.

TWINING, GEORGE E., Equipment Inspector, Western Union Telegraph Co., 302 Broadway, New York. N. Y.

VETTER, JOSEPH C., Asst. Elec. Engr., American Steel & Wire Co.; res., 257 Mercier St,, Trenton, N. J.

*WAGNER, W. H., Junior Commercial Engineer, General Electric Co.; 1026 Monadnock Bldg., Chicago, Ill.

WALDINGER, HENRY, Chief Electrician, New York *World*, 63 Park Row, New York, N. Y.

WANG, KEUI LUNG, 68 West Woodruff Avenue, Columbus, Ohio.

WEAVER, LELAND EARLE, Operating Engineer, Portland Cement Co., Newaygo, Mich.

WEIDMAN, ANTON JOSEPH, Clerk, Potomac Electric Power Co.; res., 1733 9th St., N. W., Washington, D. C.

WELSH, JOHN THOMAS, Electrical Engineer, Emergency Fleet Corp.; res., 5150 Wayne Ave., Philadelphia, Pa.

*WEST, JOHN WALTER, JR., Asst. Engineer, State Corp. Commission of Virginia, 511 Lyric Bldg., Richmond, Va.

WHITRIGHT, ROY S., Secretary & Treasurer, The Electric Motor & Repair Co., 60 Iron St., Akron, Ohio.

WILBRAHAM, FREDERICK M., Supt. of Power, The Hartford Electric Light Co., 266 Pearl St., Hartford, Conn.

WILLIAMS, FRANCIS A., Secretary & Chief Examiner, Dept. of University Extension, Mass. Board of Education, State House, Boston, Mass.

WINDERS, FRANK R., Engineering Dept., Railroad Commission of Wisconsin; res., 153 E. Gilman St., Madison, Wis.

Woodhull, S. Trubee, Engineering Manager, American Radio & Research Corp.; res., 38 Dearborn St., Medford, Mass.

Workman, Frank E., Asst. Purchasing Agent, National Carbon Co., Inc., 11700 Madison Ave., Cleveland, Ohio.

*Former Enrolled Students.

Total 177

ASSOCIATES RE-ELECTED MAY 16, 1919

Brandt, Albert U., Supt., Alameda Co. Dist., Pacific Gas & Elec. Co., 13th and Clay Sts., Oakland, Cal.

Hamilton, George Wellington, Engineer, Middle West Utilities Co., 1500 Edison Bldg., Chicago, Ill.

Maltman, J. Scott, Representative, American Electrical Works, New York, N. Y.; res., 2401 Garrison Bldg., Baltimore, Md.

MEMBERS ELECTED MAY 16, 1919

Deutsch, Edward I., Engineer, Cutler-Hammer Mfg. Co.; res., 2400 Grand Ave., Milwaukee, Wis.

***Farmer, Paul Melville**, Chief Engineer, Industrial Div., Klaxon Co.; res., 10 Washington Place, Newark, N. J.

Frantz, Louis T., Electrical Engineer, Sewerage & Water Board of New Orleans; res., 7816 Jeannette St., New Orleans, La.

Harrison, Lawrence S., Sales Engineer, P. & M. Dept., General Electric Co., New York; res., 3316 Glenwood Road, Brooklyn, N. Y.

Just, John Stephens, Engineer and Manager, City Electric Light Co., Ltd.; res., "Eruya" Simpson's Road, Paddington Heights, Brisbane, Queensland.

Sackett, Frank V., Engineer, General Fire Extinguisher Co., 1 Liberty St., New York, N. Y.

Stone, Edmund C., System Operator, Duquesne Light Co., 435 6th Ave., Pittsburgh, Pa.

TRANSFERRED TO THE GRADE OF MEMBER, MAY 16, 1919

Dobson, William P., Laboratory Engineer, Hydro Electric Power Commission of Ontario, Toronto, Ont.

Falkenburg, Eugene L., Supt. of Power, Riegos y Fuerza del Ebro, Barcelona, Spain.

Merrill, J. L., Power Specialist, Division Ship Yard Plants, Emergency Fleet Corp., Philadelphia, Pa.

Slocum, Winthrop W., Pittsburgh, Pa.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its regular monthly meeting, held on May 12, 1919, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

Andrus, Lucius B., Chief Engineer, American Public Utilities Co., Grand Rapids, Mich.

Sorensen, Royal W., Professor in Charge, Dept. of Electrical Engineering, Throop College of Technology, Pasadena, Cal.

Willis, Fred W., Deputy General Manager and Chief Engineer, Tata Hyd o-Electric Power Co. & Andhra Valley Powerr Supply Co., Bombay, India.

To Grade of Member

Lillibridge, Ray D., President, Ray D. Lillibridge, Inc., New York, N. Y.

Recommended for Transfer by the Board of Examiners, May 26, 1919

To Grade of Fellow

Rosenthal, Leon W., Vice-President, American Bosch Magneto Corp., Springfield, Mass.

To Grade of Member

Devereux, Washington, Chief of Electrical Dept., Philadelphia Fire Underwriters' Assn. Philadelphia, Pa.

Dickinson, Neville S., Electrical Engineer, Elevator Supplies Co., Hoboken; Consulting Electrical Engineer, Nairn Linoleum Co., Kearny, N. J.

Fox, Alfred C., General Superintendent, General Utilities Corp., St. Paul, Minn.

Hodge, George A., General Manager, Empreza Forca e Luz de Ribeirao Preto, Sao Paulo, Brazil.

Kleberg, Alfred L., Captain Q. M. C., Construction Division, Washington, D. C.

Kribs, Gordon, Assistant Engineer, Hydro Electric Power Commission of Ontario, Toronto, Ont.

Lindridge, Charles D., Engineer, Western Electric Co., New York, N. Y.

Muir, Roy C., Electrical Engineer, International General Electric Co., Schenectady, N. Y.

Rhodes, Sam R., Associate Professor Mechanical and Electrical Engineering, Clemson College, Clemson College, S. C.

Shoemaker, Richard W., Engineer of Distribution, Great Northern Power Co., San Francisco, Cal.

Stigant, Stanley A., Electrical Engineer, Merz & McLellan, Newcastle, England.

Tabossi, Hector, Commercial Engineer, British Thomson-Houston Co., Rugby, England.

Trust, Humphrey Gerrans, Capt. Royal Marine Engineers, Civil Engineer in Chief's Dept., Admiralty, London, England.

Turnbull, Thomas L., Consulting Engineer & General Manager, Bowness Improvement Co., Calgary, Alberta.

Vaniman, R. Lawrence, President, Produce Terminal Corp., Chicago, Ill.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before June 30, 1919.

Adams, W. C.,(Member)Montreal, Que.
Archer, H., Seattle, Wash.
Arnold, R. B., (Member), Chicago, Ill.
Aymond, W. E., Natchetoches, La.
Barrett, J. E., Fresno, Cal.
Barth, E. A., Great Lakes, Ill.
Bassett, H. B., E. Pittsburgh, Pa.
Blair, E. F., Cleveland, O.
Bound, P. T., Hamilton, Ont.
Brown, N. E., Los Angeles, Cal.
Brueggeman, R. C., Elizabeth, N. J.
Bushnell, O. J., (Member), Chicago, Ill.
Campbell, W. W., Seattle, Wash.
Carpenter, F. B., Parrish, Ala.
Cansfield, C. E., Toronto, Ont.
Catlin, H. L., Erie, Pa.
Cayo, A. B., Portland, Ore.
Collison, A. B., Baltimore, Md.
Conley, B. L., Blandville, W. Va.
Cooper, R. S., Connellsville, Pa.
Cottrell, W. J., Portland, Ore.
Cottom, C. I., Pittsburgh, Pa.
Crouse, G. B., (Member), Brooklyn, N. Y.
Currie, K. D., Baltimore, Md.
Cutting, M. B., Philadelphia, Pa.
Davies, V. L., Joliet, Ill.
de Clamecy, P., Hyde Park, Mass.
Des Camp, E. J., Seattle, Wash.
Detzer, H. E., Milwaukee, Wis.
Devlin, I. E., Chicago, Ill.
Doane, F. G., Groton, Conn.
Eastburn, A. C., Washington, D. C.
Elliott, H. F., Palo Alto, Cal.
Eshelby, A. W., Seattle, Wash.
Ferguson, J. W., Seattle, Wash.
Fiske, H. B., (Member), Montreal, Que.
Flesher, I., Connellsville, Pa.
Foster, H., St. Catharines, Ont.
Gaiside, H., Philadelphia, Pa.
Gear, C. M., Connellsville, Pa.
Gibson, W. A., Muscle Shoals, Ala.
Goddard, G. T., Chicago, Ill.
Gregg, J. M., Milwaukee, Wis.
Hagen, C., Portland, Ore.
Hall, W. S., So. Chicago, Ill.

Harrison, F. P., (Fellow), Flat Rock, N. C.
Harrison, M. A., Watertown, S. Dakota
Hawley, J. T., (Member), Joliet, Ill.
Hayden, C. C., Oswego, Ore.
Heppenstall, T. E., Copper Cliff, Ont.
Hoard, G. L., Seattle, Wash.
Horton, W. E., Boston, Mass.
Hughes, J. W., Montreal, Que.
Jefferson, H. F., (Member), Seattle, Wash.
Jobes, H. L., Boston, Mass.
Jones, A. A., Baltimore, Md.
Kalwitz, H. C., Chicago, Ill.
Kellam, C. J., (Member), Newark, N. J.
Keniston, F. H., Boston, Mass.
Kimmel, W. L., Spokane, Wash.
Kivlin, J. F., Saylesville, R. I.
Koepke, E. C., Camp A. A. Humphreys, Va.
Lane, F. A., Gloucester, Mass.
Lang, G. E., Westport, Md.
Leonard W. W., Baltimore, Md.
Levy, M. N., Brooklyn, N. Y.
Littlefield, W. B., Boston, Mass.
Mack, P. S., Schenectady, N. Y.
MacDermott, S. S., New York, N. Y.
Mackenzie, W., St. Catharines, Ont.
Maloy, J. S., Connellsville, Pa.
Mansfield, L. E., Atlanta, Ga.
Mann, W. J., Jr., Baltimore, Md.
Medicus, G. H., Baltimore, Md.
Miller, C. G., Washington, D. C.
Miller, W. C., Detroit, Mich.
Moore, W. L., Connellsville, Pa.
Morrison, G., St. Catharines, Ont.
Mueller, G. C., New York, N. Y.
Munson, P. B., Seattle, Wash.
McBan, P. F., Spokane, Wash.
McKechnie, A., Seattle, Wash.
McMillan, H. W., W. Burlington, Iowa
Neelands, W. O., Toronto, Ont.
Nelson, R. E., Kaukauna, Wis.
O'Brien, C. M., Cushing, Okla.
O'Brien, J. A., Baltimore, Md.
Olson, V. O., Naugatuck, Conn.
Opitz, C. P., Renton, Wash.
Palmer, J. P., Schenectady, N. Y.
Papamarco, D., Brooklyn, N. Y.
Paterson, A. J. J. S., Toronto, Ont.
Pearson, E. H., Minneapolis, Minn.
Pedersen, O., Chicago Hts., Ill.
Peterson, A. H., (Member), Chicago, Ill.
Peterson, C. A., Chicago, Ill.
Picker, F. C., St. Louis, Mo.
Pierson, W. V., Baltimore, Md.
Price, C. W., Baltimore, Md.
Rands, H. A., Portland, Ore.
Rannels, S. C., Parksburg, Pa.
Ratz, E. G., Hamilton, Ont.
Reid, M. W., New York, N. Y.
Reyes, H. B., Schenectady, N. Y.
Robinson, G., Cleveland, Ohio
Roedel, W. G., Springfield, Mass.
Rhoades, W. R., Sunbury, Pa.
Roys, P., Jr., Glens Falls, N. Y.
Ruble, L. S., Portland, Ore.
Sappington, R. D., Niagara Falls, Ont.
Schmeisser, E. G., Baltimore, Md.
Schulz, P. H., Milwaukee, Wis.
Scranton, K. L., Rochester, N. Y.
Shank, L. D., (Member), Centerville, Md.
Shuck, G. R., Seattle, Wash.
Shull, Boston, Mass.
Sibley, E. F., New Haven, Conn.
Simpson, J., Toronto, Ont.
Smith, D. O., Jesup, Ga.
Smith, F. W., Washington, D. C.
Smith, J. E., Elizabeth, N. J.
Smith, J. J., Pittsfield, Mass.
Smith, N. B., Connellsville, Pa.
Spiruta, F. J., Akron, Ohio
Stephenson, O. P., E. Pittsburgh, Pa.
Streiff, A., Portland, Ore.
Strieby, M. S., Pittsburgh, Pa.
Studer, W., New York, N. Y.
Stull, R. J., San Francisco, Cal.
Tibbitts, F. A., Boston, Mass.
Tobey, A. A., Portland, Ore.
Tuttle, A. E., New York, N. Y.
Van der Bent, W. S., Bloomfield, N. J.
Vandersluis, W. M., Chicago, Ill.
Van Osten, J. W., New York, N. Y.
Warring, R. C., Boston, Mass.
White, W. A., Portland, Ore.
Wile, S. G., Toronto, Ont.
Wilson, J. G., Dunbar, Pa.
Wohlgemuth, M. J., Pittsburgh, Pa.
Young, W. E., Toronto, Ont.
Total 141

Foreign Applications

Blakeley, G. P. W., Islington, Canterbury, N. Z.
de Goicoechea, L., Havana, Cuba.

Douglas, A., Manchester, Eng.
Dyer, J. L., Balboa, C. Z.
Flores, O., Sao Paulo, Brazil
Grimes, J. H., Balboa Heights, C. Z.
Hattis, R. E., Balboa Heights, C. Z.
Little, D., (Member), Melbourne, Aus.
Maass, D., Pedroso, Matanzas, Cuba
Shaw, N. N., Balboa, C. Z.
Tatekawa, H., Fuken, Shimaken, Japan
Yasukawa, D., Fukuokaken, Japan
Total 12.

STUDENTS ENROLLED MAY 16, 1919

10264 England, G. L., Univ. of Ill.
10265 Hatch, B. G., Univ. of Ill.
10266 Jepson, M., Ohio No. Univ.
10267 Kayler, K. W., Case School of Applied Science
10268 Baker, F. S., Wentworth Inst.
10269 Wexelstein, L., Univ. of Wash.
10270 Kraut, S. B., Univ. of Wash.
10271 Richards, A. H., Jr., Univ. of Ariz.
10272 Krimm, H. R., N. Y. Elec. School
10273 Chiu, W. Y., Mass. Inst. of Tech.
10274 Smith, W. E., Ga. School of Tech.
10275 Simmons, J. H., Ga. School of Tech.
10276 Russell, R. L., Ga. School of Tech.
10277 Rowland, G. W., Ga. School of Tech.
10278 Daniel, L. C., Ga. School of Tech.
10279 Lane, R. S., Stevens Inst. of Tech.
10280 Tainaka, B. K., Univ. of Wash.
10281 Geldmeier, H. F., Armour Inst. of Tech.
10282 Seyferlich, W. M., Armour Inst. of Tech.
10283 Jirka, F. J., Univ. of Ill.
10284 Foster, J. C., Univ. of Wash.
10285 Forrest, . R., Tri-State Coll.
10286 Swanson, E. W., Univ. of Minn.
10287 Sonneborn, D. B., Johns Hopkins Univ.
10288 Hancock, M. L., Johns Hopkins Univ.
10289 Osborn, O. E., Oregon Agr. Coll.
10290 Cottrell, C. L., George Washington Univ.
10291 Epstein, H., Armour Inst. of Tech.
10292 Sullivan, J. J., Univ. of Notre Dame
10293 Hocker, W. W., Univ. of Mo.
10294 Fisher, R. C., Univ. of Wash.
10295 Mattson, N. E., Univ. of Wash.
10296 Angove, C. V., Univ. of Wash.
10297 Jenkins, H. M., Swarthmore Coll.
10298 Knutt, A., N. Y. Elec. School
10299 Glauber, S. E., Columbia Univ.
10300 Manigaulk, E. L., Clemson Agr. Coll.
10301 Martin, A. F., Jr., Clemson Agr. Coll.
10302 Power, R. M., Clemson Agr. Coll.
10303 Leslie, A. E., Clemson Agr. Coll.
10304 Fitzgerald, J. B., Clemson Agr. Coll.
10305 Bunch, E. T., Clemson Agr. Coll.
10306 Brown, H. W., Clemson Agr. Coll.
10307 Chambliss, P. B., Clemson Agr. Coll.
10308 Clark, J. R., Clemson Agr. Coll.
10309 Gray, J. L., Clemson Agr. Coll.
10310 Hammond, J. A., Clemson Agr. Coll.
10311 Glenn, W. T., Jr., Clemson Agr. Coll.
10312 Day, R. E., Clemson Agr. Coll.
10313 Holley, A. F., Clemson Agr. Coll.
10314 Johnston, J. F., Clemson Agr. Coll.
10315 McCord, W. L., Clemson Agr. Coll.
10316 Morecock, E. M., Clemson Agr. Coll.
10317 McDermid, J. A., Clemson Agr. Coll.
10318 Quattlebaum, W. M., Clemson Agr. Coll.
10319 Rode, N. F., Clemson Agr. Coll.
10320 Roper, C. P., Clemson Agr. Coll.
10321 Shuler, C. L., Clemson Agr. Coll.
10322 Smith, E. R., Clemson Agr. Coll.
10323 Tollison, P. L., Clemson Agr. Coll.
10324 Voight, J. P., Clemson Agr. Coll.
10325 Wilkins, R. F., Clemson Agr. Coll.

10326 Walker, A. R., Clemson Agr. Coll.
10327 Dula, A. H., Clemson Agr. Coll.
10328 Black, J. M., Clemson Agr. Coll.
10329 Black, M. J., Clemson Agr. Coll.
10330 Allison, J. W., Clemson Agr.Coll.
10331 Ballenger, A. R., Clemson Agr. Coll.
10332 Bratton, R. B., Clemson Agr. Coll.
10333 Bartlett, C. A., Purdue Univ.
10334 Malott, L. A., Purdue Univ.
10335 Kaufman, J., Mass. Inst. of Tech.
10336 Strang, H. L., Geo. Washington Univ.
10337 Thomas, P. E., Univ. of Mich.
10338 Bunting, S. C., Swarthmore Coll.
10339 Lindstrom, L. O. B., Univ. of Mich.
10340 Andrew, G. W., N. Y. Electrical School
10341 Cover, H. T., Penn. State Coll.
10342 Lund, C., School of Engg. of Milwaukee
10343 Trant, J. L., Univ. of NotreDame
10344 Despres, J. A., Columbia Univ.
10345 Clarke, G. R., Univ. of Mich.
10346 Mitchell, J. A., R. I. State Coll.
10347 Fairbanks, G. H., R.I. State Coll.
10348 Brunner, Fred P., School of Engg. of Milwaukee
10349 Manahan, M. J., School of Engg. of Milwaukee
10350 Rick, G., School of Engg. of Milwaukee
10351 Hildreth, C. T., R. I. State Coll.
10352 Doub, C. T., Johns Hopkins Univ.
10353 Carpenter, P. M., R. I. State Coll.
10354 Pullan, E., Univ. of Toronto
10355 Fitzgerald, J. D., Univ. of Notre Dame
10356 French, C. L., Wentworth Inst.
10357 Sam, H., School of Engg. of Milwaukee
10358 Young, W. G., Georgia School of Tech.
10359 Woolcock, R.S.,Penn. State Coll.
10360 Hauer, T. M., Drexel Inst.
10361 Pennypacker, R., Drexel Inst.
10362 Zerbe, P. J., Drexel Inst.
10363 McAdam, W. R., Univ. of Wash.
10364 Shepherd, R. L., Yale Univ.
10365 Hunt, O. H., Univ. of Wash.
10366 Wyman, L. E., Engg. School of Milwaukee
10367 McNulty, J. M., Univ. of Notre Dame
10368 Cetrule, N., Cooper Union
10369 Scofield, J. J., Lewis Inst.
10370 Nechin, A., Lewis Inst.
10371 Brown, J. O., Clemson Coll.
10372 Ford, C. R., Clemson Coll.
10373 McHugh, J. F., Clemson Coll.
10374 Thompson, F. M., Clemson Coll.
10375 Wade, J. L., Clemson Coll.
10376 Coffman, O. G., Ohio No. Univ.
10377 Startzman, H. H., Johns Hopkins Univ.
10378 Painter, J. S., Kans. State Agr. Coll.
10379 McCracker, G. W., Kans. State Agr. Coll.
10380 Gfeller, L. F., Kans. State Agr. Coll.
10381 Kapp, C. A., Univ. of Cincinnati
10382 St. Clair, W. K., Montana State Coll.
10383 Shryock, C. S., Univ. of Cincinnati
10284 O'Connell, S. G., Wentworth Inst.
10385 Ulrey, J. W., Ohio No. Univ.
10386 Aguado, J., Johns Hopkins Univ.
10387 Rayfield, J. E., Central Tech. School of Toronto
10388 Forbare, L. P., Central Tech. School of Toronto
10389 Allanson, H. E, Toronto Tech. School
10390 Watson, F. W., Central Tech. School of Toronto
10391 Shannon, H. S., Central Tech. School of Toronto
Total 128

PERSONAL

Mr. Earl Wheeler announces the establishment of the firm of Wheeler, Mechlin and Rhea with offices in West Street Bldg., New York. The firm conducts an advisory and purchasing engineering business and furnishes service to foreign and domestic clients purchasing machinery and engineering materials in the United States to be used to construct, maintain and operate properties.

J. C. **Hail**, for the last three years electrical-engineer-in-charge of the Bureau of Electrical Engineering of the Department of Gas and Electricity of the City of Chicago was given a farewell banquet by his co-workers in the department, on Thursday evening, April 24, at the Grand Pacific Hotel. Mr. Hail's activities for the last three years have been principally confined to the engineering supervision of the $3,750,000 addition to Chicago's electric street lighting system. Mr. Hail leaves the service of the City of Chicago to join the Pierce Electric Co. of Chicago, Contracting Electrical Engineers who are expanding their organization.

J. G. **Berger** will have under his direction the newly established office of L. K. Comstock & Co., at 518 Kinney Building, Broad and Market Sts., Newark, N. J. This office will engage in the sale of complete industrial and power equipments as well as construction service.

Geo. W. Cravens has left Gov't Service and will establish himself independently as a Consulting Engineer with headquarters in Westfield, New Jersey and a branch office in New York City. Mr. Cravens was Automotive Engineer in the Maintenance Division of the Motor Transport Corps, Washington, D. C., and has had a wide general experience along mechanical, electrical and automotive lines. Upon leaving the army he was granted a commission as Major in the Reserve Corps.

William S. Murray formerly of New Haven, Connecticut announces the removal of his offices to 165 Broadway, New York. Mr. Murray offers consultation on electrical generation and transmission, railroad electrification and conservation of natural resources.

William McClellan has been elected a Vice-President of the Cleveland Electric Illuminating Co. The enlarged activities of the company necessitated additional executive help and led to Mr. McClellan's election. He is a graduate of University of Pennsylvania has had a varied experience in all departments of engineering construction work for public utilities, was Chief of the Division of Light, Heat and Power of the Up-State Public Service Commission of New York for three years, and was dean of the Wharton School of Finance and Commerce, Univ. of Pennsylvania.

Major George F. Sever, Engineers, U. S. A., has been honorably discharged from the United States Army after a service of fifteen months and will make his headquarters in New York City for Consulting Engineer practise. Major Sever during his service made extensive and detailed investigations of the electric power conditions in New England as well as on the Pacific Coast from Seattle to Los Angeles. His investigations covered careful analyses of the production of power by coal, oil and water, and the comparisons of these different methods.

Frank F. Fowle, until recently one of the receivers of the Central Union Telephone Company and formerly consulting engineer, and James R. Cravath, consulting electrical and illuminating engineer of Chicago, have formed an engineering partnership under the firm name of Fowle and Cravath, with offices in the Monadnock Block, Chicago. The services of the firm will be devoted to investigations, research, design, supervision, management, appraisals and rate cases.

Ralph W. Krass, formerly with the National Conduit & Cable Company, has become associated with the Westinghouse Electric & Mfg. Co., Power Department, 165 Broadway, New York City.

Major Carl A. Heinze has just returned from France where he has been serving for the past year with the A. E. F. as Commanding Officer of the 2nd Battalion, 108th Engineers. He participated in the Somme offensive at Amiens while brigaded with the British, in the Meuse Argonne action with the French at Verdun, with the American forces in front of Metz and finally was stationed in Luxemburg as part of the Army of Occupation. Major Heinze will now resume his duties as Assistant Electrical Engineer, in charge of distribution, of the Bureau of Power & Light of the City of Los Angeles.

OBITUARY

George T. Hanchett for many years prominent as a consulting electrical engineer in New York died on May 6 after a considerable period of sickness. Mr. Hanchett was admitted to the Institute in 1896 and transferred to Fellow in 1913.

Captain Charles J. Moore, 7th Engineers, U. S. A. was mortally wounded on October 14, 1918 and died on October 16, 1918. He was buried just back of the lines at Fromerèville, four miles northwest of Verdun. Captain Moore was awarded the Distinguished Service Cross for gallantry in action the morning he was wounded. His company had laid bridges across Andon River under heavy fire, then attacking and completely routing the Prussian Guard.

Previous to entering army service Capt. Moore was an Instructor in the School of Engineering, Oklahoma A. & M. College. He was elected an Associate in the Institute in 1916.

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Farley Osgood, Percy H. Thomas.

JOINT COMMITTEE ON STANDARD THREAD FOR INSULATORS AND INSULATOR PINS

J. T. Barron

AMERICAN COMMITTEE ON ELECTROLYSIS.

Bion J. Arnold, F. N. Waterman,
Paul Winsor.

ON ENGINEERING COUNCIL.

H. W. Buck, N. A. Carle,
E. W. Rice, Jr., Comfort A. Adams,
C. E. Skinner.

ENGINEERING DIVISION, NATIONAL RESEARCH COUNCIL.

Frank B. Jewett W. R. Whitney.

ON ENGINEERING FOUNDATION BOARD.

Frank B. Jewett, E. W. Rice, Jr.

ON NAVAL CONSULTING BOARD.

Benjamin G. Lamme, Frank J. Sprague

ON AMERICAN ENGINEERING STANDARDS.

Comfort A. Adams, N. A. Carle,
H. M. Hobart.

AMERICAN BUREAU OF WELDING

W. L. Merrill

COMMISSION OF WASHINGTON AWARD

Charles F. Scott John Price Jackson.

LOCAL HONORARY SECRETARIES.

Guido Semenza, N. 10 Via S. Radegonda, Milan, Italy.
Robert Julian Scott, Christchurch, New Zealand.
T. P. Strickland, 61 Hunter St., Sydney, N. S. W.
W. G. T. Goodman, Adelaide, South Australia.
James S. Fitzmaurice, Adelaide, South Australia.
L. A. Herdt, McGill Univ., Montreal, Que.
Henry Graftio, Ministry of Ways of Communication, Petrograd, Russia.
A. S. Garfield, 10 Rue de Londres, Paris, France.
Harry Parker Gibbs, Tata Hydroelectric Power Supply Co., Ltd., Bombay, India.
John W. Kirkland, Johannesburg, South Africa.

LIST OF SECTIONS

Revised to June 1, 1919

Name and when Organized	Chairman	Secretary
Atlanta...Jan. 19, '04	A. M. Schoen	Thomas C. Taliaferro, S. E. Underwriters Ass'n., Atlanta, Ga.
Baltimore...Dec. 16, '04	J. B. Whitehead	L.M.Potts,Industrial Bldg.,Baltimore,Md.
Boston...Feb. 13, '03	Ira M. Cushing	Ira M. Cushing, 84 State St.,Boston,Mass
Chicago...1893	C. A. Keller	A. P. Riggs, 1020 Monadnock Block, Chicago, Ill.
Cleveland...Sept. 27, '07	C. S. Ripley	R. W. Knowles, 1127 East 145th Street, Cleveland, Ohio.
Denver...May 18, '15	Robert B. Bonney	Norman Read, 828 Symes Bldg., Denver, Colo.
Detroit-Ann Arbor...Jan. 13, '11	George E. Lewis	A. S. Albright, Detroit Edison Company, Detroit, Mich.
Erie...Jan. 11, '18	J. C. Barry	P. B. Mansfield, Lawrence Park,.Erie, Pa.
Fort Wayne...Aug. 14, '08	P.C.Morganthaler	O. B. Rinehart, 1211 W. Jefferson Street, Fort Wayne, Ind.
Indianapolis-Lafayette .Jan. 12, '12	G. B. Schley	William H. Beck, Room 85, State House, Indianapolis, Ind.
Ithaca...Oct. 15, '02	Alexander M.Gray	John G. Pertsch, Jr., Cornell Univ.,Ithaca, N. Y.
Kansas City, Mo....Apr. 14, '16	W. P. Barnes	W. P. Barnes, 1012 Baltimore Ave., Kansas City, Mo.
Los Angeles...May 19, '08	J. H. Cunningham	Clem A. Copeland, Bureau of Power and Light, Los Angeles, Cal.
Lynn...Aug. 22, '11	L. E. Underwood	Fred E. Ewart, General Electric Company, West Lynn, Mass.
Madison...Jan. 8, '09	James W. Watson	L. E. A. Kelso, University of Wisconsin, Madison, Wis.
Milwaukee...Feb. 11, '10	F. A. Coffin	P. J. Mayer, Wisconsin Tel. Co., Milwaukee, Wisc.
Minnesota...Apr. 7, '02	Meyer Barnert	J. D. Marshall, 510-3rd Ave., So., Minneapolis, Minn.
Panama...Oct. 10, '13	W. L. Hersh	M. P. Benninger, Box 174, Balboa Heights, C. Z.
Philadelphia...Feb. 18, '03	W. P. James	E. B. Tuttle, Bell Tel. Co. of Pa., 1631 Arch St., Philadelphia, Pa.
Pittsburgh...Oct. 13, '02	W. R. Work	J. G. Carroll, General Engineering Division, W. E. & M. Co., Pittsburgh, Pa.
Pittsfield...Mar. 25, '04	Neil Currie, Jr.	N.F.Hanley,Gen.Elec.Co.,Pittsfield,Mass.
Portland, Ore....May 18, '09	R. M. Boykin	W. D. Scott, Pacific Tel. and Tel. Co., Portland, Oregon.
Rochester...Oct. 9, '14	R. H. Manson	W. C. Freeman, Stromberg Carlson Telephone, Mfg. Co., Rochester, N. Y.
St. Louis...Jan. 14, '03	J. L. Hamilton	H. G. Hake, Washington University, St. Louis, Mo.
San Francisco...Dec. 23, '04	J. C. Clark	A. G. Jones, 811 Rialto Building, San Francisco, Cal.
Schenectady...Jan. 26, '03	K. A. Pauly	L. F. Millham, General Electric Company, Schenectady, N. Y.
Seattle...Jan. 19, '04	J. Harisberger	T. C. Smith, Lighting Dept., Seattle, Wash.
Spokane...Feb. 14, '13	George Nixon	G. H. Hoppin, 1128 W. Kiernan Ave., Spokane, Wash.
Toledo...June 3, '07	W. A. Hill	Max Neuber, 1257 Fernwood Ave., Toledo, Ohio.
Toronto...Sept. 30, '03	A. H. Hull	Daniel M. Fraser, Canadian General Electric Co., Toronto, Ont.
Utah...Mar. 9, '17		H. T. Plumb, General Electric Co., Newhouse Bldg., Salt Lake City, Utah.
Urbana...Nov. 25, '02	A. R. Knight	E. H. Waldo, Univ. of Illinois, Urbana,Ill.
Vancouver...Aug. 22, '11	R. F. Hayward	T. H. Crosby, Canadian Westinghouse Co. Vancouver, B. C.
Washington, D. C....Apr. 9. '03	J. E. Smith	Milton Flanders, Bliss Elec. School, Tacoma Park, Washington, C. D.

Total 34

LIST OF BRANCHES

Name and when Organized	Chairman	Secretary
Agricultural and Mech. College of Texas...Nov. 12, '09	F. V. Murrah	C. R. Drake, A. & M. College of Texas, College Station, Tex.
Alabama Poly. Inst....Nov. 10, '16	W. W. Hill	E. E. Terry, Alabama Polytechnic Inst., Auburn, Ala.
***Alabama, Univ. of**...Dec. 11, '14		
Arkansas, Univ. of...Mar. 25, '04	Wm. L. Teague	B. R. Askew, 240 Arkansas Ave., Fayetteville, Ark.
Armour Institute...Feb. 26, '04	E. H. Arnold	M. F. Bacon, 3408 Michigan Ave.,Chicago Ill.
Brooklyn Poly. Inst....Jan. 14, '16	E. A. Demonet,Jr.	Thos. C. Schwab, Polytechnic Institute, Brooklyn, N. Y.
Bucknell University...May 17, '10	C. J. Anthor	H. H. Angell, Bucknell University, Lewisburg, Pa.
California, Univ. of...Feb. 9, '12	A. E. McMahon	D. D. Davis, University of California, Berkeley, Cal.
Carnegie Inst. of Tech...May 18, '15	L. C. Young	B. C. Dennison, Carnegie School of Technology, Pittsburgh, Pa.
Cincinnati, Univ. of...Apr. 10, '08	G. F. Embshoff	Chas. B. Hoffmann, University of Cincinnati, Cincinnati, O.
Clarkson Col. of Tech....Dec. 10, '15		
***Clemson Agric. Col.**...Nov. 8, '12		

*Inactive at present, due to the war.

Name and when Organized	Chairman	Secretary
Colorado State Agricultural College........Feb. 11, '10		
Colorado, Univ. of.....Dec. 16, '04	A. S. Anderson	T. C. Smith, 1153 Pleasant St., Boulder, Colo.
Drexel Institute........Apr. 11, '19	J. I. Ellman	F. J. Hartmann, Drexel Institute, Philadelphia, Pa.
Georgia School of Technology..............June 25, '14	R. S. Griffith	G. L. Jones, Georgia School of Technology, Atlanta, Ga.
***Idaho, Univ. of**........June 25, '14		
***Iowa, Univ. of**........May 18, '09		
***Kansas State Agr. Col.**.Jan. 10, '08		
***Kansas Univ. of**......Mar 18, '08		
Kentucky, State Univ. of Oct. 14, '10	A. D. Hall	C. A. Timmer, 315 S. Limestone, Lexington, Ky.
Lafayette College......Apr. 5, '12	Frank Wilson Ross	Chas. Spencer Allen, 909 Northampton, St., Easton, Pa.
Lehigh University......Oct. 15, '02	E. T. Petrik	F. G. Macarow, Lehigh University, S. Bethlehem, Pa.
Lewis Institute.........Nov. 8, '07		
Maine Univ. of.........Dec. 26, '06	R. C. Hopkins	L. R. Douglass, University of Maine, Orono, Me.
Massachusetts Inst. of Tech................Apr. 13, '17	Harmon B. Deal	Florence Fogler, Mass. Inst. of Tech., Cambridge, Mass.
Michigan Agric. Coll. ..Mar. 15, '18	R. A. Shenefield	W. A. Siefert, Michigan Agri. College, East Lansing, Mich.
Michigan, Univ. of.....Mar. 25, '04	P. Verschoor	A. L. Christie, University of Michigan, Ann Arbor, Mich.
Minnesota, Univ. of....May 16, '16	Oscar C. Lee	J. R. Heinemann, University of Minnesota, Minneapolis, Minn.
Missouri Univ. of......Jan. 10, '03	A. C. Lanier	W. H. Moore, University of Missouri, Columbia, Mo.
Montana State Col......May 21, '07	Jas. M. McElwee	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of.....Apr. 10, '08	Olin J. Ferguson	Oskar E. Edison, University of Nebraska, Lincoln, Nebraska.
North Carolina Col. of Agr. and Engg........Feb. 11, '10		J. G. Leonard, N. C. College of Agri. and Engg., West Raleigh, N. C.
North Carolina, Univ. of.Oct. 9, '14	W. E. Merritt, Jr.	John E. Lear, Chapel Hill, N. C.
North Dakota, Univ. of.Feb. 15, '17		
***Norwich University** ...June 28, '16		
Notre Dame, Univ. of..Feb. 19, '19	James M. Reid	J. A. Caparo, University of Notre Dame, Notre Dame, Ind.
Ohio Northern Univ....Feb. 9, '12	J. E. Summers	C. K. South, Ohio Northern University, Ada, Ohio.
Ohio State University..Dec. 20, '02	R. L. Shumaker	G. E. Park, Ohio State University, Columbus, Ohio.
***Oklahoma Agricultural and Mech. Col.**.......Oct. 13, '11		
Oklahoma, Univ. of....Oct. 11, '12		
Oregon Agr. Col.........Mar. 24, '08	L. Fudge	O. L. Cantrall, Oregon Agricultural College Corvallis, Ore.
Penn. State College....Dec. 20, '02	E. W. Taylor	C. K. Mast, Pennsylvania State College, State College, Pa.
Penn., Univ. of........Apr. 11, '19	W. H. McIntyre	J. M. Ryan, Univ. of Pennsylvania, Philadelphia, Pa.
Pittsburgh, Univ. of ...Feb. 26, '14	L. P. Kennedy	H. O. Chan, University of Pittsburgh, Pittsburgh, Pa.
Purdue University .....Jan. 26, '03	L. A. Malott	T. K. Hartley, Purdue Univ. Lafayette, Indiana.
Queen's University (Ont.) Jan. 11, '18		
Rensselaer Poly. Inst...Nov. 12, '09	W. J. Williams	L. B. Raynor, Rensselaer Polytechnic Inst. Troy, N. Y.
***Rose Polytechnic Inst.**.Nov. 10, '11		
***Stanford Univ.**.........Dec. 13, '07		
Syracuse Univ..........Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse University, Syracuse, N. Y.
***Texas, Univ. of**.......Feb. 14, '08		
Throop College of Technology.............Oct. 14, '10	Mark Sawyer	Russell Otis, Throop College of Technology, Pasadena, Cal.
Virginia Polytechnic Institute..............Jan. 8, '15	J. A. Carr	L. D. Fry, Virginia Polytechnic Inst., Blacksburg, Va.
Virginia, Univ. of ......Feb. 9, '12	J. E. B. Stuart	J. Arthur Evans, University of Virginia, University, Va.
Wash. State Col. of....Dec. 13, '07	C. E. Guse	Ralph C. Guse, State College of Washington, Pullman, Wash.
Washington Univ........Feb. 5, '04	W. J. Skrainka	H. T. Lange, Washington University, St. Louis, Mo.
Washington, Univ. of ..Dec. 13, '12	J. R. Tolmie	Glen H. Walker, University of Washington, Seattle, Wash.
West Virginia Univ......Nov. 13, '14		
***Worcester Poly. Inst.**..Mar. 25, '04		
Yale University........Oct. 13, '11	P. C. O'Brien	Donald F. Hine, 114 Whitney Ave., New Haven, Conn.

***Inactive at present, due to the war** **Total 61**

PROCEEDINGS

OF THE

American Institute of Electrical Engineers

Vol. XXXVIII
Number 7

JULY, 1919

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TABLE OF CONTENTS

Section I.—Institute Affairs

The Lake Placid Convention 247
Development of the Institute 253
A. I. E. E. Directors' Meeting, Lake Placid Club, June 25, 1919 255
Future A. I. E. E. Meetings 256
Bill to Establish a Federal Department of Public Works 257
Classification and Compensation of Engineers 258
American Engineering Standards Committee. Statement Regarding Reorganization 260
Conference on Commercial and Engineering Training 262
Correction of Error in 1918 Edition of National Electrical Code 263
Broad Scientific Research Program Advocated by American Federation of Labor 263
Vocational Training for Crippled Soldiers, Sailors and Marines 263
National Research Fellowships in Physics and Chemistry 264
Election of Officers—Illuminating Engineering Society 264
Fifth National Exposition of Chemical Industries 264
Past Section Meetings 265
Past Branch Meetings 266
Engineering Service Bulletin 268
Engineering Societies Library 273
Associates Elected June 25, 1919 275
Associates Reelected June 25, 1919 287
Members Elected June 25, 1919 287
Fellow Elected June 25, 1919 288
Transferred to Grade of Fellow June 25, 1919 288
Transferred to Grade of Member June 28, 1919 288
Recommended for Transfer 288
Applications for Election 288
Students Enrolled June 25, 1919 290
Personal 291
Obituary 292
Addresses Wanted 293

Section II.—Papers and Reports

Cooperation. (President's Address). By C. A. Adams, Lake Placid Club, N. Y., June 24, 1919 877
The Absolute Measurement of the Intensity of Sound. By A. G. Webster, Boston, Mass., March 14, 1919 889
Annual Reports of Technical Committees 901

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GEORGE R. METCALFE, Editor.

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American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXVIII **JULY, 1919** **Number 7**

ANNNAL CONVENTION

Lake Placid Club, N. Y., June 24-27, 1919.

The 35th annual convention of the Institute which was held at the Lake Placid Club, June 24-27, 1919, was well attended and thoroughly enjoyed by the members and guests present. While the chief object of the convention was the presentation and discussion of engineering papers and consideration of Institute policies, the program this year differed from those of former years, in the fact that the business and entertainment features were about evenly balanced, and this innovation met with general approval. The location of the convention was an ideal one and the natural beauties of the Adirondacks in addition to the numerous amusement features at the Lake Placid Club afforded ideal conditions for recreation.

The technical sessions, while fewer in number than usual, included subjects of live engineering interest which elicited thorough discussions. The conferences on Institute policies, under the auspices of the Committee on Development were largely attended and the tentative report of the committee was discussed at considerable length.

The members and guests registered totaled 404 including 103 ladies, which is a record figure for a summer resort convention of the Institute. A complete list of members and guests in attendance is published elsewhere in this issue.

The Board of Directors of the Institute held its usual monthly meeting on Wednesday afternoon and considered many matters of importance.

The Meetings and Papers Committee held meetings on Thursday and Friday mornings for the purpose of formulating plans for future Institute meetings.

Members of several other committees of the Institute held numerous informal conferences during the Convention.

SECTION DELEGATES

Thirty of the Sections of the Institute were represented at the Convention by delegates, as provided in the Institute Constitution. The usual conferences of the delegates were, however, merged with conferences under the auspices of the Committee on Development of the Institute; and these conferences which constituted one of the most important features of the Convention, as affecting the future policies and activities of the Institute, are reported elsewhere in this issue.

TUESDAY

The opening session of the Convention was called to order by President Adams who, after a few words of welcome presented his presidential address on "Cooperation." The full text of this address is published in Section II of this issue of the PROCEEDINGS.

The next item on the program was the introduction of the President-elect, Calvert Townley by President Adams. In responding, Mr. Townley spoke briefly referring to the part engineers had played in the war, saying that if engineers could do enough towards destruction to win the war, what could they not do in the way of construction to make the world and its people better and happier? In conclusion he stated:

> There is no sweeter honor to any man than to be chosen a leader among his own kind, among his friends, among those who believe in what he believes in, who think as he does, who speak his language, and I would be lacking in appreciation and courtesy if I did not now try, lamely, to express to you the gratitude which I feel in having conferred upon me the great honor. But in this great Institute of ours, honor is an incident, and of very secondary importance. We don't exist to honor any man or to honor any set of men; we exist for a useful purpose and we have the most wonderful opportunity in the world to accomplish a useful purpose; standing as one of the foremost engineering organizations in the land, in a country which we believe stands at the head of the world, our opportunity for doing things is unequalled.
>
> Therefore, much as I prize the very great honor you have conferred on me, I value still more the opportunity which you have given me to help you do things and I want to leave that simple thought with you.

Mr. Farley Osgood, Chairman of the convention, next announced the program of sports and games, after which the presentation of the technical papers was taken up.

The first paper on the program, *Present Day Practise of Transmission and Tie Line Relay Protection*, by H. R. Woodrow, D. W. Roper, O. C. Traver and P. MacGahan, was abstracted by Mr. Woodrow, and as the two other papers scheduled for this session were upon allied subjects they were presented next, as follows: *Grounding the Neutral of Generating and Transmission Systems*, by H. R. Woodrow, read by the author, and *Grounded-Neutral Transmission Line*, by William E. Richards, which in the absence of the author was read from manuscript by O. C. Traver.

The discussion which followed occupied the balance of the morning session and was on motion, carried over to Wednesday morning. Those who took part in the discussion were: H. B. Vincent, J. R. Craighead, J. A. Johnson, A. H. Lawton, H. C. Albrecht, Philip Torchio, P. M. Lincoln, Charles P. Steinmetz, E. T. Moore, F. D. Newbury, W. deL. Carr, R. F. Schuchardt, E. E. F. Creighton, H. C. Don Carlos, E. H. McKenzie, R. R. Honaman, E. G. Merrick, D. W. Roper, P. H. Adams, A. E. Silver, F. C. Hanker, J. C. Parker, O. C. Traver and H. R. Woodrow.

Tuesday afternoon was devoted to outdoor sports, automobile rides for the ladies and other amusements, and in the evening a reception by the President and other officers of the Institute was followed by dancing until a late hour.

WEDNESDAY

The technical program for Wednesday was confined to the presentation of the Annual Report of the Technical Committees. Before taking up these reports however the postponed discussion on "relay practise" and the "grounded neutral" was opened and considerable additional discussion of Tuesday's paper was offered. The balance of the session was devoted to the presentation and discussion of the Committee Reports which are printed in full elsewhere in this issue, and to a general discussion on the duties and functions of the technical committees. The consensus of opinion seemed to be that the technical committees should not confine their activities to procuring papers but should collect and correlate data, formulate rules and present extensive reviews of the developments in their respective fields. To assure continuity of this work it was suggested that active committee men be continued in office longer and that chairmen be selected from members of the previous committee.

THURSDAY

The Thursday morning session was devoted to a general conference under the auspices of the Development Committee as reported elsewhere in this issue.

FRIDAY

The technical session Friday morning was opened with the presentation of a paper by W. S. Clark and G. B. Shanklin on *High-Tension Single-Conductor Cable for Polyphase Systems*, which was followed by a paper by R. W. Atkinson on *The Dielectric Field in an Electric Power Cable*, also paper by A. E. Silver on *Problems of 220-Kilovolt Power Transmission*, and one by F. W. Peek, Jr., on *The Effect of Transient Voltages on Dielectrics-II*.

The two cable papers were discussed together. Among those who took part were H. W. Fisher, W. A. Del Mar, D. W. Roper, Philip Torchio, H. L. Wallau, W. S. Clark and G. B. Shanklin.

The paper on 220-Kilovolt Transmission was discussed by W. S. Murray, Philip Torchio, A. F. Bang, J. C. Clark, S. W. Mauger, R. M. Spurck, F. W. Peek, F. C. Hanker, G. I. Gilchrest, R. P. Jackson, H. B. Dwight, J. F. Peters, C. F. Harding, and F. F. Brand.

ENTERTAINMENT

A large part of the credit for the generally satisfactory convention was due to the excellent work of the Committee of Arrangements consisting of Messrs. Farley Osgood, Chairman, N.A. Carle, Walter A. Hall, Edward Kilburn, W. L. Merrill, A. M. Schoen, George F. Sever, W. I. Slichter, and Charles W. Stone. The committee not only made highly satisfactory plans for the comfort and entertainment of the members and guests in attendance, but was actively employed during the Convention in carrying out these plans. In addition to the events specially referred to elsewhere, there was informal dancing each evening, and there were facilities for boat trips on Lake Placid and various automobile trips for the ladies.

At a meeting of the Board of Directors held during the Convention, the following resolutions were unanimously adopted:

RESOLVED: that the Board of Directors of the American Institute of Electrical Engineers hereby expresses its hearty appreciation of the services rendered by the members of the Convention Committee in making and carrying out with gratifying success, the plans for the thirty-fifth Annual Convention, at Lake Placid Club, N. Y., June 24–27, 1919.

RESOLVED: that the Board of Directors of the American Institute of Electrical Engineers hereby expresses its hearty appreciation of the effective cooperation of the management of the Lake Placid Club, in providing for the comfort and pleasure of the members and guests in attendance at the thirty-fifth Annual Convention of the Institute, held at the Lake Placid Club, June 24-27, 1919.

On Tuesday and Friday afternoons Professor Vladimir Karapetoff, of Cornell University, favored the Institute by rendering exceedingly enjoyable piano recitals, which were highly appreciated by the members and their friends as well as by many of the other guests of the Lake Placid Club.

A feature of the Convention which was greatly enjoyed by all present was the selections rendered by the G. E. Office and Laboratory Liberty Loan Scrub Band of Schenectady, N. Y., of which Mr. John B. Taylor is leader. Twenty-two members of this band, most of them members of the Institute were present at the Convention and contributed greatly to the occasion by rendering appropriate music prior to the beginning of many of the important events. The band led the procession of members and guests from the Lake Placid Club to the baseball grounds on Thursday afternoon.

BASEBALL

The annual baseball game was scheduled for Thursday afternoon, June 26, between the "Neverwases," Captain, Farley Osgood and the "Hasbeens," Captain, Walter A. Hall. Rain stopped the game at the end of the fourth inning, at which time the score was 8 to 4 in favor of the Has Beens. Although the game could not be finished, a large and enthusiastic audience was well repaid for its attendance, as many of the plays were new to the art of baseball and consequently could not have been witnessed elsewhere. Captain Hall distinguished himself by making a home run on the first ball pitched in the game. The teams were made up as follows:

NEVERWASES

Farley Osgood, Captain, Newark, N. J.
Charles T. Mosman, Boston, Mass.
W. de L. Carr, Philadelphia, Pa.
G. A. Sawin, Newark, N. J.
P. H. Chase, Philadelphia, Pa.
E. D. Kilburn, New York, N. Y.
Ralph H. Kilner, Chicago, Ill.

George B. Thomas, New York, N. Y.
James T. Lawson, Newark, N. J.

HASBEENS

Walter A. Hall, Captain, West Lynn, Mass.
A. L. Donnelly, Philadelphia, Pa.
George O. Bason, New York, N. Y.
W. C. Kalb, Bradford, Pa.
F. A. Norris, New York, N. Y.
C. A. Adams, Cambridge, Mass.
J. L. R. Hayden, Schenectady, N. Y.
Henry E. Clifton, Schenectady, N. Y.
W. L. Upson, Schenectady, N.Y.

Umpires: N. A. Carle, Newark, N. J.; Harry Alexander, New York.

Scorer: J. J. Kline, Ft. Wayne, Ind.

PRIZE CONTESTS

Prizes for the various events were awarded as follows:

Golf: Low gross score, Mr. A. A. Brown; winner, first eight, Mr. A. A. Brown, runner-up, Mr. W. S. Murray; winner, second eight, Professor C. A. Adams, runner-up, Mr. A. H. Lawton; winner, third eight, Mr. W. J. Foster, runner-up, Mr. J. W. Upp; winner, fourth eight, Mr. W. E. Holcombe, runner-up, Mr. G. B. Shanklin.

Mr. Brown's victory entitles him to have his name inscribed on the Mershon Golf Trophy, which will become the property of the first person who succeeds in winning the golf tournament at two Institute conventions. It has previously been won by Mr. A. M. Schoen, of Atlanta; J. C. Mock, of Detroit; E. W. W. Allen, of Chicago; and L. F. Deming, of Philadelphia.

Tennis: Doubles won by Messrs. K. D. and L. W. Fisher, Perth Amboy, N. J.; runners up, Mr. John Murphy, Ottawa, and Jerome Taylor, Schenectady. The single tournament was not finished, on account of rain. Messrs. T. S. Knight, of Boston, and G. A. Sawin, of Newark, N. J., had won their way to the finals.

Ladies' Putting Contest: First, Mrs. N. M. Garland, New York; second, Mrs. E. J. Cheney, Albany; booby prize, Mrs. I. M. Cushing, Boston.

Lucky Dancing Contest: Mrs. G. B. Shanklin, Schenectady, and Mr. Wallace S. Clark, Schenectady.

Ladies' Card Party: Bridge: First, Mrs. N. M. Garland, New York, second, Mrs. Wm. T. Poulterer, Philadelphia. Hearts: First, Mrs. Harry Alexander, New York; Second, Mrs. E. K. Shelton, Pittsfield.

MEMBERS AND GUESTS IN ATTENDANCE

A

Adams, Mr. and Mrs. C. A., Cambridge, Mass.
Adams, Mr. and Mrs. P. H., Newark, N. J.
Albrecht, H. C., Philadelphia, Pa.
Alexander, Mr. and Mrs. Harry, New York, N. Y.
Alexanderson, Mr. and Mrs. E. F. W., Schenectady, N. Y.
Allcutt, C. T., Pittsburgh, Pa.
Allen, Elbert G., Boston, Mass.
Allen, E. W., Chicago, Ill.
Alverson, H. B., Buffalo, N. Y.
Andrus, L. B., Grand Rapids, Mich.
Annett, F. A., New York, N. Y.
Apperson, J. S., Schenectady, N. Y.
Argersinger, R. E., Boston, Mass.
Armbrust, G. M., Chicago, Ill.
Atkinson, R. W., Perth Amboy, N. J.
Axell, C. G., Chicago, Ill.

B

Baker, W. R. G., Schenectady, N. Y.
Barnert, Meyer, St. Paul, Minn.
Barnes, H. H., Jr., New York, N. Y.
Bason, George O., New York, N. Y.
Beebe, L. S., Schenectady, N. Y.
Beekman, R. A., Schenectady, N. Y.
Belt, T. A. E., Schenectady, N. Y.
Bentley, Mr. and Mrs. R. O., Newark, N. J.
Berresford, Mr. and Mrs. A. W., Milwaukee, Wis.
Bliss, O. J., Chicago, Ill.
Bonnett, Mr. and Mrs. L. B., Schenectady, N. Y.
Boorzhinsky, N. P., New York, N. Y.
Boyd, Paul, Schenectady, N. Y.
Boykin, Richard M., Portland, Ore.
Bradish, C. B., Schenectady, N. Y.
Brand, F. F., Pittsfield, Mass.
Braymer, Mr. and Mrs. D. H., New York, N. Y.
Brinton, Mr. and Mrs. H. G., Pittsfield, Mass.
Brobst, John E., Schenectady, N. Y.
Brooks, W. L., Schenectady, N. Y.
Brown, Arthur A., New York, N. Y.

C

Carle, Mr. and Mrs. N. A., Newark, N. J.
Carr, W. de L., Philadelphia, Pa.
Carter, W. A., Denver, Colo.
Chamberlin, Mr. and Mrs. G. N., Swampscott, Mass.
Chase, Mr. and Mrs. P. H., Philadelphia, Pa.
Cheney, Mr. and Mrs. Edward J., Albany, N. Y.
Cheyney, Mr. and Mrs. Edward L., Cleveland, O.
Chubb, L. W., Pittsburgh, Pa.
Chubbuck, L. B., Hamilton, Can.
Clark, J. C., Palo Alto, Cal.
Clark, John W., Schenectady, N. Y.
Clark, Wallace S., Schenectady, N. Y.

Clarke, Mr. and Mrs. Charles L., Schenectady, N. Y.
Clifton, Henry E., Schenectady, N. Y.
Connell, Mr. and Mrs. B. R., Schenectady, N. Y.
Cook, C. F., Schenectady, N. Y.
Cook, James A., New York, N. Y.
Craft, Mr. and Mrs. E. B., New York, N. Y.
Craighead, Mr. and Mrs. J. R., Schenectady, N.Y.
Crawford, W. J., Buffalo, N. Y.
Creighton, E. E. F., Schenectady, N. Y.
Crichton, L. N., Pittsburgh, Pa.
Cullingworth, F. J., Newark, N. J.
Cummins, A. R., Pittsburgh, Pa.
Currie, Neil, Jr., Pittsfield, Mass.
Curtiss, Miss H. E., Schenectady, N. Y.
Curtiss, John L., Syracuse, N. Y.
Cushing, Mr. and Mrs. Ira, Boston, Mass.

D

Dann, Walter M., Pittsburgh, Pa.
Davey, Wheeler P., Schenectady, N. Y.
Davis, Mr. and Mrs. C. M., Schenectady, N. Y.
Davison, A. E., Toronto, Ont.
Dean, Mr. and Mrs. H. C., New York, N. Y.
Dearborn, R. H. and child, Corvallis, Ore.
DelMar, William A., New York, N. Y.
Doherty, R. E., Schenectady, N. Y.
Don Carlos, H. C., Toronto, Ont.
Donnelly, Mr. and Mrs. Aug. L., Philadelphia, Pa.
Durston, Mr. and Mrs. A. G., Syracuse, N. Y.
Dwight, H. B., Hamilton, Ont.

E

Eby, Mr. and Mrs. Eugene D. and child, Pittsfield, Mass.
Eden, Mr. and Mrs. T. S., Schenectady, N. Y.
Ekern, E. A., Cambridge, Mass.
Ellis, Mr. and Mrs. A. L., Swampscott, Mass.
Elmendorf, Mrs. A., So. Orange, N. J.
Ewart, Frank R., Toronto, Ont.

F

Faccioli, G., Pittsfield, Mass.
Febrey, H. H., Newark, N. J.
Farmer, F. M., New York, N. Y.
Feiker, F. M., New York, N. Y.
Fetherstonhaugh, E. P., Winnipeg, Man.
Finucane, B. E., Rochester, N. Y.
Fisher, Mr. and Mrs. H. W., Perth Amboy, N. J.
Fisher, K. D., Perth Amboy, N. J.
Fisher, L. W., Perth Amboy, N. J.
Foster, Mr. and Mrs. W. J., Schenectady, N. Y.
Fries, Mr. and Mrs. J. E., Birmingham, Ala.

G

Gale, Frank H., Schenectady, N. Y.
Gardner, Miss Ida, Wilmington, N. Y.
Garland, Mr. and Mrs. N. M., New York, N. Y.
Gilbert, S. D., Swampscott, Mass.
Gilchrest, Geo. I., Pittsburgh, Pa.
Gilt, Carl M., Schenectady, N. Y.
Greason, Mrs. T. R., Wilmington, N. Y.
Griggs, Miss Mary A., Somerville, N. J.
Griggs, Mrs. James L., Somerville, N. J.
Goodwin, E. R., Albany, N. Y.

H

Hall, Mr. and Mrs. Walter A., Lynn, Mass.
Hamilton, Mr. and Mrs. J. L., St. Louis, Mo.
Hamilton, George, St. Louis, Mo.
Hamilton, James A., St. Louis, Mo.
Hanker, F. C., Wilkinsburg, Pa.
Hansson, Mr. and Mrs. Axel S., Paris, France
Harding, A. L., New York, N. Y.
Harding, C. Francis, La Fayette, Ind.
Harisberger, John, Seattle, Wash.
Hartshorne, W. B., Hackensack, N. J.
Hayden, Mr. and Mrs. J. L. R. and 2 children, Schenectady, N. Y.
Henderson, John S., Syracuse, N. Y.
Henderson, S. E. M., Toronto, Ont.
Henry, Percy C., Massena, N. Y.
Hewett, John R., Schenectady, N. Y.
Hixson, Mr. and Mrs. C. J., Schenectady, N. Y.
Hoe, Miss C. E., New York, N. Y.
Holcombe, Mr. and Mrs. W. E., Schenectady, N. Y.
Honaman, R. Karl, Washington, D. C.
Hopton, Mrs. N. W.
Hull, Arthur H., Toronto, Ont.
Hunt, F. L., Greenfield, Mass.
Hutchinson, F. L., New York, N. Y.
Hyde, Edw. P., Cleveland, Ohio.

I

Imlay, Mr. and Mrs. L. E., Niagara Falls, N. Y.
Ingalls, W. A., Syracuse, N. Y.

J

Jackson, Jas. A., Schenectady, N. Y.
James, William F., Philadelphia, Pa.
Jewett, Mr. and Mrs. F. B., New York, N. Y.
Johnson, J. A., Niagara Falls, N. Y.
Jones, C. A., Brooklyn, N. Y.

K

Kalb, W. C., Bradford, Pa.
Karapetoff, Mr. and Mrs. Vladimir, Ithaca, N. Y.
Kelsey, Charles A., Schenectady, N. Y.
Keyes, Dudley H., New York, N. Y.
Keyes, Mr. and Mrs. F. A., New York, N. Y.
Kilburn, Mr. and Mrs. Edw. D., New York, N. Y.
Kilmer, Ralph H., Chicago, Ill.
Kline, J. J., Ft. Wayne, Ind.
Klumpp, Mr. and Mrs. J. B., Philadelphia, Pa.
Knight, A. R., Urbana, Ill.
Knight, Mr. and Mrs. C. D., Glen Ridge, N. J.
Knight, Thomas S., Boston, Mass.

L

Lanier, A. C., Columbia, Mo.
Lawson, James T., Newark, N. J.
Lawton, A. H., Jackson, Mich.
Lemp, Herman, Jr., Erie, Pa.
Lewis, W. W., Schenectady, N. Y.
Lewry, H. B., New York, N. Y.
Libby, Donald M., Schenectady, N. Y.
Lincoln, P. M., Pittsburgh, Pa.
Linebaugh, Mr. and Mrs. J. J., Schenectady, N.Y.
Linebaugh, John V., Schenectady, N. Y.
Logan, H., New York, N. Y.
Logan, Mr. and Mrs. Harry B., New York, N. Y

M

Mac Calla, Mr. and Mrs. C. S., Schenectady, N.Y.
Macdonald, J. E., Los Angeles, Cal.
MacDowell, A. S., Rochester, N. Y.
Macfarlane, Mr. and Mrs. J. C., Toronto, Ont.
Mac Gahan, Paul, Pittsburgh, Pa.
Maclachlan, Wills, Toronto, Ont.
Martindale, E. H., Cleveland, O.
Marvin, R. H., E. Liverpool, O.

Matson, John J., Schenectady, N. Y.
Mauger, Mr. and Mrs. S. W., Schenectady, N. Y.
Mayer, Frank J., Milwaukee, Wis.
McAllister, A. S., New York, N. Y.
McCurdy, R. G., New York, N. Y.
McDowell, C. S., New London, Conn.
McKenzie, D. A., Toronto, Ont.
McKibben, F. W. J., Syracuse, N. Y.
McRae, Mr. and Mrs. F. G., Glens Falls, N. Y.
McRae, Donald C., Glens Falls, N. Y.
Mercer, G. G., Schenectady, N. Y.
Merrick, Mr. and Mrs., E. G. Schenectady, N. Y.
Merrill, Mr. and Mrs. W. L., Schenectady, N. Y.
Metcalfe, G. R., New York, N. Y.
Meyer, Mr. and Mrs. E. B., Newark, N. J.
Millham, L. F., Schenectady, N. Y.
Moody, Mr. and Mrs. Walter S., Pittsfield, Mass.
Moody, Miss Jean, Pittsfield, Mass.
Mooney, P. P., Jackson, Mich.
Moore, Mr. and Mrs. Edward T., Syracuse, N. Y.
Morehouse, Mr. and Mrs. L. F., New York, N. Y.
Mosman, Charles T., Boston, Mass.
Muir, Roy C., Schenectady, N. Y.
Murphy, John, Ottawa, Ont.
Murray, W. S., New York, N. Y.

N

Newbury, Mr. and Mrs. F. D., Pittsburgh, Pa.
Nicholson, L. C., Buffalo, N. Y.
Nixon, George, Spokane, Wash.
Noble, P. O., Schenectady, N. Y.
Norris, F. A., New York, N. Y.
Nutt, A. M., Massena, N. Y.
Nutt, F. A., Massena, N. Y.

O

Ober, D. C., Cleveland, Ohio.
Ohashi, F., Schenectady, N. Y.
Oliver, C. R., Worcester, Mass.
Oliver, R. H., Schenectady, N. Y.
Osborne, Mr. and Mrs. L. A., Stockbridge, Mass.
Onken, W. H., Jr., Brooklyn, N. Y.
Osgood, Mr. and Mrs. Farley, Newark, N. J.

P

Parker, John C., Ann Arbor, Mich.
Peck, Mr. and Mrs., F. W. Jr., Pittsfield, Mass.
Perkins, Thos. S., Pittsburgh, Pa.
Perry, Allen M., New York, N. Y.
Perry, Mr. and Mrs. C. L., Schenectady, N. Y.
Peters, J. F., Pittsburgh, Pa.
Place, E., Schenectady, N. Y.
Pollard, Mr. and Mrs. N. L., Newark, N. J.
Poth, Miss Lucille, Perth Amboy, N. J.
Potts, Mr. and Mrs. L. M., Baltimore, Md.
Poulterer, Mr. and Mrs. Wm. Taylor, Philadelphia, Pa.
Pratt, Harlan A., Plainfield, N. J.
Pratt, Mr. and Mrs. W. H., Lynn, Mass.
Purton, T. A., Salt Lake City, Utah.

R

Raymond, C. S., Schenectady, N. Y.
Reiner, Milton, Baltimore, Md.
Reyneau, P. O., Detroit, Mich.
Ring, Dr. H. W., New York, N. Y.
Ripley, Mr. and Mrs. C. S., Cleveland, Ohio.
Robbins, Charles, Pittsburgh, Pa.
Robinson, Mr. and Mrs. L.T.,Schenectady, N.Y.
Roper, D. W., Chicago, Ill.
Rose, G. S., New York, N. Y.
Rushmore, David B., Schenectady, N. Y.
Russell, Gladys, Chicago, Ill.

S

Sawin, Mr. and Mrs. G. A., Montclair, N. J.
Schermerhorn, H. L., Scotia, N. Y.
Schoen, A. M., Atlanta, Ga.
Schuchardt, R. F., Chicago, Ill.
Schum, Mr. and Mrs. C. H., Erie, Pa.
Sclater, Ivanhoe H., Pittsfield, Mass.
Scott, C. F., New Haven, Conn.
Sever, George F., New York, N. Y.
Shanklin, Mr. and Mrs. G. Bryan, Schenectady, N. Y.
Sharp, C. H., White Plains, N. Y.
Shepard, Mr. and Mrs. Bert H., Syracuse, N. Y.
Shelton, Mr. and Mrs. Edward K., Pittsfield, Mass.
Sill, F. J., Worcester, Mass.
Silver, A. E., Montclair, N. J.
Silver, B. L., Montreal, Can.
Simmons, B. F., Holyoke, Mass.
Skinner, Mr. and Mrs. C. E., Pittsburgh, Pa.
Slichter, Mr. and Mrs. W. I., New York, N. Y.
Smith, Mr. and Mrs. A. R., Schenectady, N. Y.
Smith, George B., Belleville, Ont.
Smith, Paul H., Syracuse, N. Y.
Sparr, Victor W.
Spalding, H. K., New York, N. Y.
Sprong, Mr. and Mrs. S. D., Brooklyn, N. Y.
Spurck, R. M., Schenectady, N. Y.
Stanley, Howard A., Fall River, Mass.
Steinmetz, Chas. P., Schenectady, N. Y.
Stetler, A. M., Rochester, N. Y.
Stewart, Mr. and Mrs. F. J. T., New York, N. Y.
Stone, Mr. and Mrs. F. L., Schenectady, N. Y.
Stotz, John K., Pittsburgh, Pa.
Stoughton, F. A., Massena, N. Y.
Summer, Mr. and Mrs. M. D., Buffalo, N. Y.
Summerhayes, H. R., Schenectady, N. Y.
Summerhayes, John, Schenectady, N. Y.
Sykes, C. B., Schenectady, N. Y.
Sykes, Wilfred, Pittsburgh, Pa.

T

Talmadge, E. E., Schenectady, N. Y.
Tanzer, E. Dean, Philadelphia, Pa.
Tackett, C. A., St. Louis, Mo.
Tappan, F. G., Norman, Okla.
Taylor, Mr. and Mrs. J. B., Schenectady, N. Y.
Tatum, L. L., Milwaukee, Wis.
Taylor, Jerome J., Schenectady, N. Y.
Taylor, Telford, Schenectady, N. Y.
Teare, Mrs. H. P., Summit, N. J.
Thayer, C. S., New York, N. Y.
Thomas, George B., Maplewood, N. J.
Thompson, F., Buffalo, N. Y.
Todd, Victor H., Orange, N. J.
Torchio, Philip, New York, N. Y.
Townley, Calvert, New York, N. Y.
Traver, Mr. and Mrs. O. C., Schenectady, N. Y.
Twitchel, R. S., Boston, Mass.

U

Uhl, Arthur W., Brooklyn, N. Y.
Underhill, Mr. and Mrs. C. R., New Haven,Conn.
Underwood, L. E., Lynn, Mass.
Unland, H. L., Schenectady, N. Y.

Upp, Mr. and Mrs. John W., Schenectady, N. Y.
Upson, W. L., Schenectady, N. Y.

V

Vail, A. E., Massena, N. Y.
Van Dyke, Mr. and Mrs. C. S., Schenectady, N.Y.
Varney, Theodore, Pittsburgh, Pa.
Vincent, H. B., Philadelphia, Pa.
Voyle, C. C., Gainesville, Fla.
Voyle, Miss M., Gainesville, Fla.

W

Wagner, R. T., Schenectady, N. Y.
Wallau, Mr. and Mrs. H. L., Cleveland, Ohio.
Waller, Mr. and Mrs. A. E., Mt. Vernon, N. Y.
Watson, J. W., Madison, Wis.
Wayne, J. Lloyd, 3rd, Indianapolis, Ind.
Webster, O. F., Buffalo, N. Y.
Williamson, Mr. and Mrs. R. B., Milwaukee, Wis.
Williamson, Mrs. H. H., Philadelphia, Pa.
Wood, Mr. and Mrs. O. D., Pittsfield, Mass.
Wiseman, Robt. J., Yonkers, N. Y.
Wood, Claude O., Schenectady, N. Y.
Woodrow, Mr. and Mrs. H. R., New York, N. Y.
Worcester, Mr. and Mrs. T. A., Schenectady, N.Y.
Work, William R., Pittsburgh, Pa.
Total 404

DEVELOPMENT OF THE INSTITUTE

No events at the Annual Convention of the Institute, held at the Lake Placid Club June 24–27, exceeded in importance the conferences that were held under the auspices of the Institute's Development Committee.

On Wednesday morning, June 26, the Section delegates had a brief meeting and unanimously voted to merge the conferences regarding Institute activities, which are usually held by the delegates each year, with the meetings referred to below which were held under the auspices of the Development Committee.

The delegates in attendance at the Convention were as follows:

Atlanta	*Schoen, A. M.
Baltimore	Potts, L. M.
Boston	*Cushing, Ira M.
Chicago	*Schuchardt, R. F.
Cleveland	Ripley, C. S.
Denver	Carter, W. A.
Detroit-Ann Arbor	*Parker, J. C.
Erie	*Schum, C. H.
Fort Wayne	*Kline, J. J.
Indianapolis-Lafayette	*Wayne, J. L., 3rd
Ithaca	Karapetoff, V.
Los Angeles	*MacDonald, J. E.
Lynn	*Underwood, L. E.
Madison	*Watson, J. W.
Milwaukee	Mayer, F. J.
Minnesota	Barnert, Meyer
Philadelphia	*James, Wm. F.
Pittsburgh	Work, W. R.
Pittsfield	Currie, N., Jr.
Portland, Ore.	Boykin, R. M.
Rochester	*MacDowell, A. S.
St. Louis	Hamilton, J. L.
San Francisco	*Clark, J. C.
Schenectady	Millham, L. F.
Seattle	*Harisberger, J.
Spokane	Nixon, George
Toronto	Hull, A. H.
Utah	Purton, T. A.
Urbana	Knight, A. R.
Washington, D. C.	Honaman, R. K.

*Also members of Development Committee.

The members of the Development Committee in attendance in addition to those indicated above in the list of delegates, were as follows:

Brand, F. F., Pittsfield, Mass.
Del Mar, W. A., New York, N. Y.
Ewart, Frank R., Toronto, Ont.
Hall, W. A., West Lynn, Mass.
Lincoln, P. M., Pittsburgh, Pa.
Robinson, L. T., Schenectady, N. Y.
Scott, C. F., New Haven, Conn.
Townley, Calvert, New York, N. Y.
Wallau, H. L., Cleveland, Ohio.

DEVELOPMENT COMMITTEE'S CONFERENCES

Three sessions were held under the auspices of the Development Committee. The first of these, at luncheon on Wednesday, June 25, consisted of a conference of members of the Development Committee, the delegates of the Institute Sections, the officers, members of the Board of Directors, and a few others particularly interested in the important subjects under discussion. The remaining two sessions were open to all members of the Institute attending the Convention.

At the first conference the Executive Committee of the Development Committee presented a tentative report to the entire Development Committee, for the purpose of obtaining discussion for use in formulating a report of the Development Committee to the Board of Directors of the Institute embodying recommendations regarding the Institute's activities. The discussion continued throughout the afternoon.

At the first session, on Thursday morning, June 26, Mr. Calvert Townley, Chairman of the Development Committee, presented the tentative report of the Development Committee with such amendments as had been agreed upon at the meeting of the previous afternoon. The remainder of this session and the entire evening session of the same day were devoted to general discussion of the recommendations suggested in the tentative report and amendments.

Chairman Townley explained that the Development Committee had been at work for about six months, and that through publication of statements by the President of the Institute and the Chairman of the Development Committee in the Institute PROCEEDINGS, every member of the Institute had been requested to forward suggestions to any member of the Development Committee; also that all the Sections of the Institute had been invited and urged by the Development Committee to hold special sessions for the purpose of discussing the activities of the Institute and what, if any, changes are desirable, and that more than half of the Sections had held such meetings and presented summaries of their discussions to the Development Committee; also that many individual members had communicated their views to the Development Committee; and that all suggestions received through Sections or individuals had received the consideration of the Development Committee. Furthermore, that there was a very general demand for certain changes in some of the more important activities of the Institute; and that, in formulating this tentative report, the Executive Committee had included these fundamental matters only and had not attempted to make recommendations relating to the large number of individual suggestions received, all of which, will however receive further consideration later by reference to the appropriate committees of the Institute.

The plan proposed by the Executive Committee for the continuance of the work, was to formulate after hearing the discussion at the Convention, a report to the Board of Directors embodying recommendations to meet the clearly indicated demands of the membership for the improvement and development of the Institute's activities. These recommendations include:

1. Development of the scope of the monthly PROCEEDINGS in order to include, in addition to the high grade electrical engineering papers which have formed the principal part of the PROCEEDINGS up to the present time, other material of more general interest, without in any way lowering the Institute's standards.

2. Inclusion in the monthly publication of a set of abstracts of practically all papers presented at Section meetings throughout the country.

3. Consideration of whether or not a satisfactory plan can be developed which will eliminate the present wasteful practise of printing practically all papers twice, once in the monthly PROCEEDINGS and again in the annual TRANSACTIONS, by possibly printing the monthly in two sections, bound together in one publication when issued and so arranged that they may be separated later by the recipient, who may wish to dispense with the transient matter and retain the part containing technical papers and discussions of permanent value.

4. As a result of the improvement of the monthly publication, it will become a better advertising medium; and it is suggested that advantage be taken of this fact to develop the advertising section and thereby meet the additional cost of enlarging the editorial staff and printing more material.

5. Create a New York Section, organized and conducted along the same lines as existing Sections elsewhere.

6. Extend the present practise of holding some of the Institute and Directors' meetings in different parts of the country where local Sections are

established, instead of holding nearly all of these meetings in New York as at present.

7. Divide the country into geographical divisions corresponding in number with the number of Institute Vice-Presidents; and select one Vice-President from each of these districts.

8. Make it a part of the duty of each Vice-President to visit the Sections in his own division at least once a year.

9. Pay the traveling and living expenses of the officers and Board members attending Institute meetings.

10. Increase the Vice-Presidents' term of office from one year to two years. Provide that no member of the Board of Directors may continuously hold office for more than six years.

11. Decentralize committee work as far as may be found feasible and desirable, by substituting Section committees for some of the Institute committees. Appoint a general committee to study this question and to make recommendations.

12. Present more high grade papers of general engineering interest.

13. Create a committee in each Section charged with the duty of assigning to the younger members specific participation in designated meetings by the preparation of papers and discussions, or otherwise. By this and other methods, including appointment of a reasonable number of the younger men to membership on committees, it is hoped to stimulate the interest of the younger members and thereby increase their loyalty to the organization and their opportunities for self development.

14. The remainder of the tentative report related to methods of cooperation between the Sections of the Institute and sections of other societies, and local engineering organizations; and also to cooperation by the national organizations. In general, it was recommended that all of these questions be taken up through a joint conference committee of the development committees of the four national societies of civil, mining, mechanical, and electrical engineers, and plans have already been made to do this.

While many suggestions were made during the discussions, all of which will receive further consideration by the Development Committee before formulating its report to the Board of Directors, the general result was embodied in a resolution passed at the final session, on Friday evening, to the effect that all the recommendations of the Development Committee were approved in principle, with the understanding that details would be worked out by appropriate committees at a later date.

Summarizing all of the discussions regarding Institute affairs at the Convention, the results were exceedingly gratifying, indicating a high degree of interest in the work of the Institute; and there is every indication that as a result of the work of the Development Committee and the membership at large, the activities of the Institute will be modified and extended to meet the generally expressed wishes of the membership. The complete report of the Development Committee to the Board of Directors will be published in a later issue of the PROCEEDINGS.

A. I. E. E. DIRECTORS' MEETING LAKE PLACID CLUB, JUNE 25, 1919

The regular monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held at the Lake Placid Club, N. Y., Wednesday, June 25, 1919, at 4:00 p.m.

There were present: President C. A. Adams, Cambridge, Mass.; Vice-Presidents F. B. Jewett, New York, John B. Taylor, Schenectady; Managers C. E. Skinner, Charles Robbins, Wilfred Sykes, F. D. Newbury, Pittsburgh, N. A. Carle, Newark, N. J., E. H. Martindale, Cleveland, W. A. Hall, West Lynn, Wm. A. Del Mar, W. I. Slichter, New York, G. Faccioli, Pittsfield; Secretary F. L. Hutchinson, New York. Also, by invitation, Vice-President-elect A. M. Schoen, Atlanta, and Manager-elect L. F. Morehouse, New York.

The action of the Finance Committee in approving monthly bills amounting to $16,313.02, was ratified.

The Finance Committee presented a revised budget for the appropriation year ending September 30, 1919, which was approved, to supersede the budget adopted in October 1918. The change in the estimate of both receipts and disbursements was due to the changed conditions on account of the termination of the war.

It was voted that a committee be appointed by the President to formulate a plan for dealing with loyal employees of the Institute who are incapacitated from service on account of illness or otherwise.

The following resolution was adopted:

> RESOLVED: that the Board of Directors of the American Institute of Electrical Engineers hereby expresses to the members of the Membership Committee its hearty appreciation of the effective work of that Committee, applications for membership having been received from 1710 candidates during the year ending June 1, 1919.

Chairman Slichter of the Meetings and Papers Committee reported orally that programs were practically arranged for the following meetings: Pacific Coast Convention, Los Angeles, September 18-20; joint meetings with American Physical Society in Philadelphia, Oct. 10 and with the Institute of Radio Engineers in New York, Oct. 1; and a meeting under the auspices of the Power Stations Committee in New York in November.

Reports were presented of meetings of the Board of Examiners held May 26 and June 16, 1919; and the actions taken on applications at those meetings were approved. Upon the recommendation of the Board of Examiners the following action was taken upon pending applications: 48 Students were ordered enrolled; 358 applicants were elected to the grade of Associate; 9 applicants were re-elected to the grade of Associate; 18 applicants were elected to the grade of Member; 1 applicant was elected to the grade of Fellow; 10 applicants were transferred to the grade of Member; 2 applicants were transferred to the grade of Fellow.

President Adams reported orally on the conference of the Rating Committee of the International Electrotechnical Commission which he attended, with Messrs. H. M. Hobart and C. O. Mailloux, as delegates of the Institute, in Paris, May 5-7; also on the conference with the British Engineering Standards Committee which he and Mr. Hobart attended as representatives of the American Engineering Standards Committee, in London, May 26 to June 5.

A communication under date of April 22 was presented from Mr. Van H. Manning, Director, Bureau of Mines, Washington, inviting the Institute to send a delegation to attend the dedication ceremonies of the new buildings of the Pittsburgh Experiment Station of the Bureau of Mines, September 29 to October 1, 1919. The President was authorized to appoint such a delegation.

In addition to the above, many other matters relating to important activities and the general policy of the Institute were discussed and in most cases were referred to various committees and officers for further consideration. Reference to these matters may be found in this and future issues of the PROCEEDINGS under suitable headings.

FUTURE A. I. E. E. MEETINGS

Pacific Coast Convention.—The Pacific Coast Convention of the Institute will be held September 18-20, 1919 under the auspices of the Los Angeles Section.

New York Meeting.—A joint meeting with the Institute of Radio Engineers will be held in New York on October 1, 1919. The subject of this meeting will be Radio Telegraphy.

Philadelphia Meeting.—On October 10, 1919 a regular meeting of the Institute will be held in conjunction with the American Physical Society. This meeting will be under the auspices of the Electrophysics Committee.

New York Meeting.—A regular Institute meeting under the auspices of the Power Stations Committee will be held in New York on November 14, 1919.

Programs for the above meetings are now being arranged and will be given in full in future issues of the PROCEEDINGS.

BILL TO ESTABLISH A FEDERAL DEPARTMENT OF PUBLIC WORKS

A conference of technical societies was called by the Engineering Council in Chicago, April 23 to 25, to consider the establishment of a national department of public works. The conference was attended by 71 delegates representing 74 organizations with a membership in excess of 105,000. There were also 7 members of Engineering Council and 3 members of National Service Committee of Engineering Council, making the total number participating 81.

The following recommendations were adopted:

1. That the services and bureaus of the National Government having to do chiefly with matters of engineering and architecture, be grouped in one department to be known as the Department of Public Works.
2. That the Department of Public Works comprise those works which are built and operated for the use of the Public.
3. That the Department of Public Works be made available when desirable for the performance of special engineering and architectural work for the use of other Government bureaus.
4. That there be a systematic classification and organization of engineers, architects and other employees whose status shall be such that they may be recruited and maintained on merit.

Following an extended discussion of ways and means of continuing the work of the conference and promoting the passage of a bill in Congress to establish a Department of Public Works, a permanent organization was effected.

As the outcome of this meeting a bill was introduced in Congress June 25th in which the main idea is to assemble all engineering activities of the Government in one department. Under the terms of this bill the Department of Interior would become the Department of Public Works, and such bureaus of the Interior Department as are non-engineering in character are to be placed under the jurisdiction of appropriate departments, while engineering bureaus from other departments are to be included in the Department of Public Works. Some of the principal provisions of the bill are as follows:

The Patent Office is to be removed from the Interior Department and placed under the Department of Commerce. The Bureau of Pensions is assigned to the Department of the Treasury. The Bureau of Education goes to the Labor Department. The Bureau of Indian affairs also is transferred to the Department of Labor, with the proviso that the engineering and construction work and the land and mineral surveys now performed under the direction of the Bureau of Indian Affairs are to be prosecuted under the Department of Public Works. St. Elizabeth's Hospital and the Freedman's Hospital in this city are assigned to the Treasury Department. Columbia Institution for the Deaf and the Howard University go to the Bureau of Education, under the provisions of the bill.

On the other hand, the Department of Public Works is slated to absorb the Supervising Architect's Office of the Treasury Department; the Construction Division, River and Harbor Improvements, Mississippi River Commission, and California Debris Commission of the War Department; the Bureau of Standards and the Coast and Geodetic Survey of the Department of Commerce; the Bureau of Public Roads and the Forest Service of the Department of Agriculture.

The bill provides that the Secretary of Public Works "shall by training and experience be qualified to administer the affairs of the Department and to evaluate the technical principles and operations involved in the work thereof". The measure excepts from the foregoing provision the Cabinet officer who is at the head of the Department at the time of the passage of the bill.

Four Assistant Secretaries, each to be paid $7500 per annum, are provided and their duties outlined. One Assistant Secretary is to have administrative jurisdiction over all matters of engineering design and construction. Another is to have charge of architectural design and construction. The third is to have jurisdiction over all scientific work and surveys, while the fourth Assistant Secretary is to be in immediate charge of all land and legal matters. The Assistant Secretaries are charged with the duty of coordinating and bringing into efficient relationship all the activities of the department so that it may be harmoniously and efficiently administered.

An important feature of the bill is the proviso; that engineer officers of the U. S. Army detailed on non-military work are to be assigned by the Secretary of War to like duties under the new department, for not over two years. This enables the Secretary of Public Works to make gradual transfer of improvements and instrumentalities to civil administration without detriment to public interest. Members of the Corps of Engineers may, under the direction of the Secretary of Public Works, be detailed by the Secretary of War to temporary duty in the new department for such instruction, training and experience as is desired.

CLASSIFICATION AND COMPENSATION OF ENGINEERS

The Committee on Classification and Compensation of Engineers appointed by Engineering Council has made a preliminary report covering three sections, namely, Federal, Railroad, and Municipal and State Sections. The following abstract covers the principal features of the report:

Federal Government Section

A survey of Government activities shows there are 28 offices that employ Government engineers. A letter was sent to each department secretary outlining the work of the Committee and requesting assistance in furnishing a list of engineering bureaus in his department and in issuing instructions to the chiefs to furnish the needed data. Favorable responses from all departments were received, except the War Department, which stated it would be impracticable to furnish the desired information. Following the approval of the secretaries, a letter containing a questionnaire was sent to the chiefs of the engineering offices, many of whom have sent in their final reports. In order to determine salary recommendations the Committee has collected reports from various organizations which have dealt with this subject, but little work has been done yet on the analysis of the data collected as this cannot readily be done until the majority of the reports have been received.

Railroad Section

The Railroad Section reports that a questionnaire was prepared to be sent to the chief engineers of the railroads under Federal control under the supposition that the salaries of all of the men were a matter of public knowledge, and also requested recommendations on an unofficial basis from them. Before sending out this questionnaire, the Chairman made a personal call on Director-General Hines and discussed with him the propriety of making such a request. Mr. Hines did not think that the matter should be approached in the manner suggested, nor that the employer should be called upon to furnish a list of salaries and to express in advance an opinion as to how these salaries should be changed, but stated that he did not see any objection to securing information from members of the Founder Societies. The Chairman therefore has confined his questions to members of the Founder Societies.

Municipal and State Section

By reason of the wide variety of titles used for the Municipal and State service, the Committee found it necessary to undertake the formulation of a standard classification of positions and duties before attempting to investigate the question of compensation. The assistance of the Municipal Engineers of the City of New York was invoked, and after a painstaking investigation a schedule of suitable titles with corresponding qualifications and duties has been prepared. The fitness of this schedule for general use is now being considered. It is proposed to incorporate this schedule in a questionnaire for circulation among engineers of all states and important cities with a view to determining present compensation and changes which should be made.

COMPENSATION

In attempting to formulate standard rates of compensation for professional engineers, the first task is to find out what rates are actually in force, and the second is to find what adjustment should be made to correspond to the great change which has taken place in the cost of living, or, in other words, in the value of the dollar. The enormous increase in prices of the necessaries of life has been accompanied by an increase in wages especially among organized workers, but no such increase has taken place for salaried workers in the professions. Where salaries have been increased during the past three years there are few cases in which the increase has been at all commensurate with the increase in prices of the necessaries of life.

There is little doubt that a large proportion of the salaried workers in professional occupations during the past three years have been unable to pay their living expenses from their earnings and have been obliged to rely on income from property owned or to use up savings of other years in order to maintain themselves.

A serious question is whether the present scale of prices is here to stay. It appears to be the opinion of many financiers and economists that the present high prices are likely to continue for a long time, probably for several years. If these are to continue for several years then surely the salaried worker has an equitable claim to have his compensation brought back in purchasing power to what it was formerly. The Committee believes therefore that in adopting standards for the compensation of workers in all technical fields due consideration should be given to the great increase in the cost of living which has taken place. The dollar of salary must be considered with regard to what it will purchase today and what it will purchase next year, not with regard to what it would purchase 10 or 15 years ago.

Under the resolution of Engineering Council providing for the appointment of this Committee, the scope of its work is limited to the preparation of a report as to "what course of action should be pursued". It is recommended by your Committee that the resolution be amended in such a way as clearly to authorize it to carry on its investigations as now planned and to direct it to formulate a definite classification for each of the services under consideration and a schedule of compensations which might reasonably be fixed for positions in each class.

The resolution might also convey directions to the Committee to submit with its final report suggestions as to the course to be pursued, to the end that its recommendations may be generally accepted.

Upon receipt of this report the following resolutions were adopted by Engineering Council:

RESOLVED, that the Committee on Classification and Compensation of Engineers be continued as organized with three sections: (1) Federal Government, (2) Railroads, (3) Municipal; that the committee be authorized to collect information concerning existing classifications and compensations and to formulate and recommend improved schedules which may be recommended by Engineering Council for general acceptance and use.

RESOLVED, that the Committee be requested to submit with its final report suggestions as to the course to be pursued to the end that its recommendations may be generally accepted.

AMERICAN ENGINEERING STANDARDS COMMITTEE

Statement Regarding Reorganization

In many lines of engineering much excellent standardization work had been done before the war; the war emphasized its importance and showed most clearly the need of co-operation to prevent the confusion caused by the promulgation of overlapping standards by independent bodies. During the war the Government Departments coordinated these efforts in certain lines and greatly assisted in unifying them. The American Institute of Electrical Engineers, American Institute of Mining and Metallurgical Engineers, American Society of Civil Engineers, American Society of Mechanical Engineers and American Society for Testing Materials, recognizing the value of what had been done, invited the Government Departments of War, Navy and Commerce to appoint representatives to act with them to continue this work. The body so formed is the American Engineering Standards Committee. It has required considerable time to definitely formulate its objects, and to arrange methods for accomplishing them that would be effective without in any way interfering with the many organizations that have been doing such excellent work in this line.

The American Engineering Standards Committee has just completed and adopted a revision of its Constitution which has been sent to the Governing Boards of all the Departments and societies represented on the Committee with a request for its ratification.

The new Constitution changes the name to American Engineering Standards Association, the change from "Committee" to "Association" more fittingly indicating the wide scope of the interests involved.

The objects of the Association are stated as follows:

1. To unify and simplify the methods of arriving at engineering standards, to secure co-operation between various organizations and to prevent duplication of standardization work;
2. To promulgate rules for the development and adoption of standards;
3. To receive and pass upon recommendations for standards submitted as provided in the Rules of Procedure, but not to initiate, define or develop the details of any particular standard;
4. To act as a means of intercommunication between organizations and individuals interested in the problems of standardization;
5. To give an international status to approved American engineering standards;
6. To cooperate with similar organizations in other countries and to promote international standardization.

Means are provided for increasing the number of representatives in the Association by invitation or on request. Several important organizations interested in standardization will be invited to appoint representatives as soon as the necessary power is obtained.

The routine work of the Association will be conducted by its Secretary under the direction of a Board of Directors. This Board will have power to deal with all of the affairs of the Association except the final approval of the standards submitted to it.

Any organizations may request the Association to approve standards which it has formulated, or to approve committees that it has appointed, and by so doing becomes a Sponsor Society. Such a request is entirely at the option of the organization that has formulated or expects to formulate the standard. At the request of the Sponsor, approval of the standards is given when they are the substantially unanimous conclusions of a committee made up as follows:

a. Sectional Committees dealing with standards of a commercial character (specifications, shop practises, etc.), shall be made up of representatives of producers, consumers and general interests, no one of these interests to form a majority. A producer is a person, or the representative of a firm or corporation, directly concerned in the production of the commodity involved. A consumer is a person, or the representative of a firm or corporation, that uses the commodity involved, but is not directly concerned with its production. General interests include independent engineers, educators, and persons who are neither consumers nor producers, as defined above.

b. Sectional Committees dealing with standards of a scientific or non-commercial character shall consist of persons specially qualified, without regard to their affiliations.

It is anticipated that in nearly all cases the approval of standards and committees by the Association will be requested. In case it is considered advisable, the Association is authorized to call a meeting of those who would be interested in the formulation of a new standard or the revision of an old one, to select one or more Sponsor Societies. The Sponsor Society or Societies will appoint a Sectional Committee to formulate or revise the standard. This Sectional Committee will report to the Sponsor when its work is completed. The Sponsor may then request the Association to approve. The Association deals only with the Sponsor and acts only at its request. Provision is made in all publications that a standard must be referred to as that of the Sponsor, using whatever title the Sponsor has given it, followed by the statement "approved by the American Engineering Standards Association." The approval may be given in one of three ways as—Recommended Practise, Tentative Standard, or Standard, the expectation being that nothing will be approved as Standard until it has shown that it is generally acceptable.

The Association thus acts only to bring together those interested in a common object, and when they have completed their work, will at their request, certify that it has been done in such a manner as to justify its adoption. Nothing revolutionary is proposed, it is merely an extension of present practise. The Executive Committee of the American Society for Testing Materials now passes on the composition of committees, ascertains that their conclusions are substantially unanimous, and if so, reports them to the society for acceptance or rejection. The Association does the same for groups of organizations. Its Board of Directors performs the same functions as the Executive Committee of the American Society for Testing Materials, and the Association as a whole accepts or rejects. It neither selects Sponsors nor Sectional Committees; it does not consider the subject matter of a standard, nor the procedure under which it is arrived at, except that it requires sufficient information from the Sponsor to show that the conclusions are substantially unanimous and that the Sectional Committee is balanced and representative. It requires that in all publications the Sponsor shall be given full credit.

In addition to this work in assisting in the selection of committees and certifying that their work has been done under proper conditions, the Association will act as a bureau of information regarding standardization. It will collect information regarding existing standards and as to the bodies that have formulated and adopted them. This will enable it to promptly give necessary information to those who select a committee to formulate a new standard or revise an old one. It will also enable it to furnish information desired by the working committees regarding what has been or is being done on similar or related lines. It will establish relations with similar bodies in other countries and can do much to promote the acceptance of International Standards. It is possible to secure international acceptance of American Standards more easily through such a body than in any other way.

With these fundamental restrictions of its activities it may be asked whether there is sufficient reason for the existence of the Association. This naturally has been carefully considered and it is the unanimous conclusion of the committee and of all of those who have been consulted who have been active in standardization work, that such an organization is urgently needed. In the past there have been many occasions when two or more organizations have formulated standards for substantially the same thing. Often these differences have been very slight, but neither has been quite acceptable to the other party. In the majority of such cases if these organizations had been brought together at the start they could have agreed on a standard that would have been satisfactory to both. The American Engineering Standards Association will furnish a means by which any organization intending to define a standard can readily ascertain what others are interested, and should be consulted in regard to it. At present there is no such means. There is nowhere anything approaching a complete list of the organizations doing standardization work, much less any list of the standards proposed or in preparation. The enormous advantage of having any standard generally accepted, and the much greater probability of accomplishing this if it is prepared under definite conditions that have proved effective in the past, will, it is believed, cause most of the organizations engaged in such work to ask and receive the assistance of the American Engineering Standards Association. It provides definite machinery for securing co-operation and preventing duplication of work. It establishes definite rules securing the absolute autonomy of any group engaged in the development of standards and insures that this group shall receive full credit for its work.

With the assurances of co-operation that the American Engineering Standards Association has already received, we believe that there is no question of the advisability of forming the more broadly representative Association. Several organizations have already presented requests for the approval of existing standards and we are informed that many others only await the notification of the Committee that it is fully organized.

It has been impossible to make any public statement of the Committee's plans until they had been definitely formulated. This, we feel, has now been accomplished and we can therefore state what it is hoped to accomplish and the methods proposed for the purpose.

CONFERENCE ON COMMERCIAL AND ENGINEERING TRAINING

A national conference on Commercial and Engineering Training as announced in the June PROCEEDINGS, was held at Washington, D. C., June 23-24, 1919. The following resolutions which were adopted at the final session of the conference clearly reveal the drift of the discussion and constitute an endorsement of the object of the conference.

The resolutions are as follows:

It is the sense of the meeting that:

1. Industrial and commercial development has created a demand for men with technical engineering training and business ability. Manufacturing industries are seeking engineers to qualify to serve in capacities requiring sound business training. Banks and brokers also need men with business training and the engineering point of view. This need is rapidly increasing and bids fair to demand a large number of technically trained men for both domestic and foreign commerce.

2. In order to meet this demand the economic phases of engineering subjects should be emphasized wherever possible in engineering instruction. This may be done by emphasizing the problems of values and costs in the regular technical work and by introducing or extending courses in general economics, cost accounting, business organization and business law into the engineering curricular. These courses should be designed particularly to meet the needs of the engineering student.

3. The engineering phases of economic subjects should be emphasized wherever possible in commercial instruction. Students in commercial courses should also be given opportunity to take special courses in the basic principles and practises of engineering so that they may understand in general terms the operation of power plants and transportation systems from the engineering point of view.

4. It is also urged upon all institutions with departments in engineering and economics or

commerce that they consider some plan of coordination to develop a course in preparation for those careers wherein practical training in modern languages, in the essentials of engineering and business theory and practise have been found to be both helpful and necessary.

CORRECTION OF ERROR IN 1918 EDITION OF NATIONAL ELECTRICAL CODE

In the 1915 edition of the National Electrical Code the second paragraph of Rule 23, section "a" read as follows:

"Where the switch required by No. 24 "a" is inside the building, the cutout required by this section must be placed so as to protect it, unless the switch is of the knife blade type and is enclosed in an approved box or cabinet, under which conditions the switch may be placed between the source of the supply and the cutout."

Through an error this section was omitted when the 1918 edition was printed.

The Electrical Committee of the National Fire Protection Association has voted that this matter be given the widest publicity, that all interested parties may be advised that this section was omitted. The Electrical Committee would recommend that Inspection Departments approve an installation in accordance with this paragraph.

BROAD SCIENTIFIC RESEARCH PROGRAM ADVOCATED BY AMERICAN FEDERATION OF LABOR

The American Federation of Labor adopted the following resolution at its Atlantic City convention:

"WHEREAS, scientific research and the technical application of results of research form a fundamental basis upon which the development of our industries, manufacturing, agriculture, mining, and others must rest; and

WHEREAS, the productivity of industry is greatly increased by the technical application of the results of scientific research in physics, chemistry, biology, and geology, in engineering and agriculture, and in the related sciences; and the health and well-being not only of the workers but of the whole population as well, are dependent upon the advances in medicine and sanitation; so that the value of scientific advancement to the welfare of the nation is many times greater than the cost of the necessary research; and

WHEREAS, the increased productivity of industry resulting from scientific research is a most potent factor in the ever-increasing struggle of the workers to raise their standards of living, and the importance of this factor must steadily increase since there is a limit beyond which the average standard of living of the whole population cannot progress by the usual methods of re-adjustment, which limit can only be raised by research and the utilization of the results of research in industry; and

WHEREAS, there are numerous important and pressing problems of administration and regulation now faced by federal, state, and local governments, the wise solution of which depends upon scientific and technical research; and

WHEREAS, the war has brought home to all the nations engaged in it the overwhelming importance of science and technology to national welfare, whether in war or in peace, and not only is private initiative attempting to organize far-reaching research in these fields on a national scale, but in several countries governmental participation and support of such undertakings are already active; therefore be it

RESOLVED, by the American Federation of Labor in convention assembled, that a broad program of scientific and technical research is of major importance to the national welfare and should be fostered in every way by the Federal Government, and that the activities of the Government itself in such research should be adequately and generously supported in order that the work may be greatly strengthened and extended; and the Secretary of the Federation is instructed to transmit copies of this resolution to the President of the United States, to the President pro tempore of the Senate, and to the Speaker of the House of Representatives.

VOCATIONAL TRAINING FOR CRIPPLED SOLDIERS, SAILORS AND MARINES

A situation exists making it evident that thousands of soldiers, sailors and marines crippled in the service, both here and abroad, do not fully understand their rights, particularly re-education at Government expense in callings suited to their disability. Large numbers of disabled men were discharged before the Federal Board for Vocational Training began functioning, and it is now extremely difficult to reach them.

The Government is not only willing

but anxious to train disabled men, enabling them to assume again the responsibilities of civil life. While in training men will receive an amount equal at least to the base pay received during their last month's service, in no case less than $65.00 per month with additional allowances for dependents. Totally disabled men come under a special provision. On completion of training men will be assisted in obtaining employment. Men who have lost a limb will receive a permanent first class artificial limb.

The provisions outlined above are to be considered as a Government obligation and not a charity and any person coming in contact with disabled men will be doing a patriotic duty by directing them to write to the Federal Board for Vocational Training at Washington, D. C.

NATIONAL RESEARCH FELLOWSHIPS IN PHYSICS AND CHEMISTRY

The National Research Council announces further appointments to National Research Fellowships in physics and chemistry. Previously six appointments were announced, three in chemistry and three in physics. The object of the National Research Council in maintaining a system of research fellowships is to promote fundamental research in physics and chemistry primarily in educational institutions in the United States. Fellowships are awarded to persons who have demonstrated a high order of ability in research for the purpose of enabling them to conduct investigations at educational institutions which make adequate provisions for research in physics and chemistry. The new appointments are as follows:

IN CHEMISTRY

Warren C. Vosburgh, of New York City.
B.S. Union College, 1914
A.M. Union College, 1916
Ph.D. Columbia University, 1919.
Research Assistant to the Professor of Chemistry at Columbia University for the past six months.

George Scatchard, of New York City.
A.B. Amherst College, 1913
Ph.D. Columbia University, 1917.
Formerly Research Assistant to the Professor of Chemistry at Columbia University and instructor in organic chemistry; First Lieutenant, Sanitary Corps, U. S. A.

IN PHYSICS

Ernest F. Barker, of London, Canada.
B.S. University of Rochester, 1908
M.A. University of Michigan, 1913
Ph.D. University of Michigan, 1915.
Professor of Physics, Western University, London, Canada, since 1915.

Albert Edward Caswell, of Eugene, Oregon.
A.B. Leland Stanford University, 1908
Ph.D. Leland Stanford University, 1911.
Professor of Physics, University of Oregon, since 1917.

The members and acting members of the Research Fellowship Board are as follows:

Wilder D. Bancroft
Henry A. Bumstead
Simon Flexner
George E. Hale
Elmer P. Kohler
A. O. Leuschner
Robert A. Millikan
Arthur A. Noyes
E. W. Washburn

ELECTION OF OFFICERS—ILLUMINATING ENGINEERING SOCIETY

The election of the following officers of the Council for the fiscal year 1919-1920, was confirmed by the Council on June 12th, 1919. The following men were elected to fill the offices made vacant by expiration of terms: President, S. E. Doane; Vice-President, Wm. J. Clark; General Secretary, Clarence L. Law, Treasurer, L. B. Marks; Directors, E. C. Crittenden, F. E. Cady, R. B. Ely.

FIFTH NATIONAL EXPOSITION OF CHEMICAL INDUSTRIES

The Fifth Annual National Exposition of Chemical Industries will be held this year in Chicago at the Coliseum and First Regiment Armory during the week of September 22nd. In connection with the Exposition a program is in preparation which includes meetings of the American Institute of Mining

Engineers during the first part of the week, the American Ceramic Society on Wednesday September 24, the American Electrochemical Society on the 25th to 27th, and the Technical Association of Pulp and Paper Industry on the 24th to 27th.

Among the interesting features of the program will be a symposium upon Safety in Plant and Mine and a series of motion pictures made under government supervision of safety work in plant, field and mine.

PAST SECTION MEETINGS

Atlanta.—May 30, 1919, Atlanta Theatre. Subject: "Electrical Communication in War Times." Address with moving pictures by Major Edward B. Craft.

Baltimore.—April 25, 1919, Engineers' Club. Address by Mr. R. H. McLain on "The Engineer and the Public". Attendance 45.

Chicago.—May 26th, 1919, Western Society Rooms. Illustrated addresses as follows—(1) "Measuring Gas Electrically" by J. C. Wilson; (2) "Lifting Magnet Operation" by B. E. Fernow. Election of officers—chairman, A. F. Riggs; secretary, A. C. King; members of executive committee, C. A. Keller, F. F. Fowle, Gordon Fox and H. L. Caldwell. Attendance 225.

Cleveland.—May 19, 1919, Hotel Statler. Election of officers as follows —W. B. David, chairman; L. D. Bale, secretary-treasurer; Alex. M. McCutcheon, chairman, papers committee; and as members executive committee, W. D. Smoot, W. M. Skiff and R. W. Knowles.

Detroit-Ann Arbor.—May 1, 1919, Board of Commerce. Paper: "Wireless Telephony and Telegraphy in War" by A. A. Oswald. Joint meeting with the Detroit Engineering Society. Attendance 150.

Denver.—May 17, 1919, Shirley Hotel. Address by Dr. Albert C. Crehore on "Progress in Atomic Theory. Captain D. C. McClure told of engineering work with the American Army of Occupation in the Rhine district. Election of officersas follows—chairman, H. S. Evans; vice-chairman, D. C. McClure; secretary-treasurer, R. B. Bonney. Attendance 32.

Fort Wayne.—May 16, 1919—G. E. Company Building. Election of officers as follows—chairman, C. I. Hall; secretary-treasurer, O. B. Rinehart; members of executive committee, W. S. Goll, W. Howard Miller and A. F. Welch.

Ithaca.—May 16, 1919, Franklin Hall, Cornell University. Illustrated lecture by Mr. R. E. Wagner on "Electric Arc Welding". Attendance 75.

Lynn.—May 28, 1919, G. E. Hall. Address by Colonel J. M. Andrews entitled "Random Remarks about the 105th Infantry in France." Attendance 120.

Madison.—June 11, 1919, Engineering Building. Papers: (1) "Influence of Maximum Demand on Rates" by C. B. Hayden; (2) "Modern Types of Maximum Demand Meters" by F. A. Kartak. Professor C. M. Jansky elected chairman. Attendance 23.

Milwaukee.—June 11, 1919, Athletic Club. Illustrated address by Mr. Curtis on "Motion Pictures in the World's War". Attendance 85.

Panama.—June 1, 1919, Balboa Heights Election of officers as follows—chairman, William T. O'Connell; vice-chairman, Earl A. Graham; secretary-treasurer, M. P. Benninger; executive committee, B. R. Grier, C. W. Roberts, and J. T. Thibault.

Pittsburgh.—June 7, 1919, University Club. Paper: "Some Experiencesof the Fifteenth Engineers in France" by Lieut. Colonel T. H. Schoepf. Attendance 150.

Pittsfield.—April 10, 1919, New American Hotel. Paper: "The Motion Pictures Secret Part in Winning the War" by Jamison Handy. Attendance 125.

April 24, 1919, New American Hotel. Address by Colonel J. M. Andrews on "With the 105th in France". Attendance 75.

May 28, 1919, Masonic Temple. Annual Banquet of the Pittsfield Section. Dr. George Otis Smith, Director of U. S. Geological Survey, gave an address on "America's Peak Load". Attendance 218.

Portland.—May 6, 1919, Gasco Building. Address by Mr. Geo. E. Quinan on "National Electrical Safety Code". Attendance 60.

San Francisco.—May 23, 1919, Palo Alto. Paper: "Recent Development in Long Distance Radio Telegraphy" by L. F. Fuller. Election of officers as follows—chairman, W. G. Vincent; Secretary, A. G. Jones. Attendance 160.

Seattle.—April 15, 1919, Chamber of Commerce. Paper: "Analysis of Wave Forms by Means of Indicating Instruments" by L. F. Curtis. Attendance 50.

May 20, 1919, Chamber of Commerce. Paper: "High Pressure Steam Distribution System in Portland" by O. H. Le Ferre. Attendance 36.

Spokane.—May 16, 1919. Annual meeting. Dinner at Silver Grill—Technical program at Chamber of Commerce. Paper: "Development of the Airplane" by Foster Russell. Election of officers as follows—chairman, J. E. E. Royer; vice-chairman, Glenn H. Hoppin; secretary-treasurer, Foster Russell; executive committee, C. F. Uhden; R. S. Daniels, and L. J. Pospisil. Attendance 51.

St. Louis.—May 28, 1919, Engineers Club. Addresses as follows—"Methods of Measuring Insulation Resistance of Electrical Apparatus" by H. Weichsel; "Circulating Currents of D-C. Armatures", "V-Curves of Synchronous Motors", and Phase "Relation of Interconnected Polyphase Systems", by A. S. Langsdorf. Attendance 50.

Toronto.—April 25, 1919, Engineers Club. Paper: "Some Voltage Limitations of Current Transformers" by W. B. Buchanan. Election of officers as follows—chairman, A. B. Cooper; secretary, D. M. Fraser. Attendance 65.

May 16, 1919, Engineers Club. Subject: "The Metric System." Speakers: Messrs. E. F. Burton, E. V. Pannell, W. P. Dobson, C. G. Spencer, E. T. J. Brandon, W. F. McKnight, H. W. Price, Perry A. Borden and W. F. Sutherland. Attendance 60.

PAST BRANCH MEETINGS

University of Arkansas.—May 20, 1919. Papers: (1) "Electric Propulsion of Battleships" by Robert Cherry; (2) "Industrial Influence of Waterways" by S. J. Felsenthal; (3) "Electric Shocks" by Wm. L. Teague; (4) "A. I. E. E. for Past Session" by B. R. Agnew; (5) "Incandescent vs. Arc Light for Motion Pictures" by P. D. Hannah. Attendance 15.

Drexel Institute.—April 28, 1919. Paper: "The Possibility of Great Progress in Electrical Engineering During the Reconstruction Period" by Prof. Johnson. Attendance 24.

May 28, 1919. Election of officers as follows—chairman, L. R. Culver; secretary, T. J. Hartmann; treasurer, T. D. Dutton. Attendance 20.

Kansas State Agricultural College.—March 28, 1919. Paper: "Light Plants in Small Cities" by Prof. C. E. Reid. Attendance 56.

April 25, 1919. Paper: "What I Meet in Inspection Work" by Mr. Rhodes. Attendance 62.

May 9, 1919. Papers: (1) "X-Ray" by S. W. Honeywell; (2) "A Trip to Kansas City" by J. S. Painter; (3) "Resuscitation" by Prof. R. G. Kloeffier.

May 23, 1919. Election of officers as follows—president, Mr. Gulledge; vice-president, Mr. Sahlmann; secretary, Mr. Lucas; treasurer, Mr. Downer. Attendance 54.

Massachusetts Institute of Technology.—June 6, 1919. Annual Banquet. Address by Prof. D. C. Jackson on "My Recent Experiences in France." Election of officers as follows: president, Harman B. Deal; vice-president, Ralph D. Booth; secretary, Florence Fogler;

treasurer, Irving H. Wilson. Attendance 75.

University of Michigan.—May 28, 1919, Engineering Building. Illustrated lecture by Prof. A. H. Lovell on "The Engineers in the Service". Address by Mr. F. L. Snyder on "Telephone Service and Transmission". Election of officers as follows—chairman, Lester M. Ilgenfritz; vice-chairman, Gordon R. Anderson; secretary, Ross Gunn; treasurer, George Clark. Attendance 65.

Michigan Agricultural College.—May 14, 1919. Paper: "Alternating Currents", by R. D. Wyckoff. Demonstration of the osillograph. Election of officers as follows: chairman, R. D. Wyckoff; secretary-treasurer, R. B. Kling; executive committee, M. M. Cory, R. A. Shenefield, and R. W. Noddins. Attendance 10.

University of Minnesota.—May 28, 1919, Engineering Auditorium. Election of officers—chairman, Norman Kingsley; secretary, Clarence L. Nelson Attendance 35.

University of North Carolina.—Annual Banquet. Attendance 33.

Ohio Northern University.—May 19, 1919, Dukes Memorial. Election of officers as follows—chairman, Mark Jepson; vice-chairman, John Ulrey; secretary, W. L. Lynde; treasurer, Monroe Zimmerman. Attendance 17.

Ohio State University.—May 13, 1919, Robinson Laboratory. Papers: "Practical Application of Thermocouples in Hardening of Steel" by Howard P. Bish; (2) "A-C. Timing Devices" by Ralph P. Graber. Attendance 28.

May 16, 1919, University Chapel. Showing of films "The Potter's Wheel" and "Fairy Magic" through courtesy of General Electric Company. Attendance 74.

University of Pennsylvania.—May 28, 1919, Engineering Building. Annual business meeting. Addresses by Profs. C. E. Clewell, H. E. Trent, Dr. Pender and Mr. Frye. Attendance 34.

Throop College of Technology.—June 2, 1919. Address by Prof. Harris J. Ryan on "The Work of the Electrical Engineer". Attendance 200.

University of Virginia.—May 14, 1919, Peabody Hall. Motion pictures on—"Thomas Edison—The Benefactor", "Back to the Farm", and "Pittsfield Electrical Works", by courtesy of General Electric Company. Attendance 50.

University of Washington.—May 6, 1919, Forestry Hall. Papers: (1) "Design of Modern Pin Type Insulators" by W. A. Kleist; (2) "Testing of Suspension Type Insulators" by R. O. Bach. Attendance 13.

Washington University.—May 12, 1919. Papers: (1) "Lead Storage Batteries" by Geo. D. Rosenthal; (2) "Mechanical Power of Light" by Martin Frisch: (3) "Effects of Electric Shock" by Edw. Bowles. Attendance 17.

ENGINEERING SERVICE BULLETIN

Opportunities. The Institute, is particularly anxious to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in this BULLETIN. The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Services Available.—Under this heading brief announcements (not more than fifty words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office files.

Note.—Copy for publication in the BULLETIN should reach the Secretary's office not later than the 20th of the month if publication in the following issue is desired. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

Engineering Societies Employment Bureau.—This is a joint bureau under the auspices of the Engineering Council. The Institute's employment service is coordinated with that of the joint bureau.

OPPORTUNITIES FOR SERVICE

V-523. Cornell University requires some instructors in electrical engineering at salaries varying from $1000. to $1500., depending on the experience of the applicant. Apply with reference to Professor A. Gray or if especially interested in advance theory to Professor V. Karapetoff.

V-524. Lighting and starting engineer wanted by prominent manufacturer of *automotive electrical* equipment. High-grade man with both designing and production experience in electric lighting and starting. Please write fully covering in detail the following information: Education, experience, history, age and compensation.

V-525. Wanted. An electrical engineer experienced in mechanical design of electrical apparatus junction boxes, switching equipment, etc. Familiarity with spacings, contact surfaces, strength of materials, etc., essential. Position is that of chief draftsman and design engineer. A real opportunity for a man with practical design viewpoint and ability to originate designs to meet problems arising in the field. State age, nationality, experience, and salary expected.

V-526. Graduate engineer experienced in the operation of steam power and gas producer plants. The work will consist of supervising and improving the operation of such plants; which will also embrace the design and technical control of large melting, heating and annealing furnaces, heat regeneration, gas cleaning and smoke prevention. Ability to make and carry out suggestions which will reduce operating costs is particularly desired. Location Pennsylvania. Salary depends upon man.

V-527. Commercial power salesman for electric public utility. Must possess tact and have pleasing personality. Preferably a technical graduate. Duties will include solution of industrial engineering problems of customers of public utility company. Some knowledge of rates, electrical industrial equipment, and distribution practises advisable. Location West Virginia.

V-528. Power company in Middle West has opening for thoroughly experienced substation designer familiar with a-c. and d-c. layout, involving transformers, converters, 4000 to 13,000 volt cable lines, etc. Give age, experience and salary desired.

V-529. Engineer, experienced in the design of transformers. Permanent position for man who can qualify. State age, training, experience and salary expected.

V-530. Engineer, familiar with the design and application of fractional horsepower motors, both a. c. and d. c. Opportunity to develop with a rapidly growing business. In replying give experience.

V-531. Engineer, experienced in the design of induction motors. Permanent position for man able to do independent work. Please state training and experience.

V-532. Experienced designing engineers, competent to do original design work on direct-current motors and generators of small and medium sizes. In replying, state education, experience and salary expected.

V-533. Prominent manufacturer of electrical equipment for automobiles with rapidly expanding business has opportunity for high-grade man experienced in testing research and development of steel, insulating compounds and other materials used in the manufacture of small electrical appliances. Philadelphia plant, located in pleasant cool, suburban environment. Applications to receive consideration should be typewritten and include the following information which will be regarded with utmost confidence: Personal history, education, detailed experience, age, present and expected salary.

V-534. Prominent manufacturer of electrical equipment for automobiles with rapidly expanding business has opportunity for high-grade man with experience in manufacture of small accurately made mechanical appliances on large production basis. One who can plan and develop mechanical detail for efficient quantity production. Experience in *automotive electrical* field especially desirable. Philadelphia plant, located in pleasant, cool, suburban environment. Applications to receive consideration should be typewritten and include the following information which will be regarded with utmost confidence: Personal history, education, detailed experience, age, present and expected salary.

V-535. Prominent manufacturer of electrical equipment for automobiles with rapidly expanding business has opportunity for high-grade physicist with experience in electrical development and research. The organization, plant and equipment of this concern is probably the best of its kind in this country. Widely known and advertised, an organization with high standards and a quality product. Consideration will be given only to men who can appreciate these standards and policies and who will make them theirs. Philadelphia plant, located in pleasant, cool, suburban environment. Applications to receive consideration should be typewritten and include the following information which will be regarded with utmost confidence: Personal history, education, detailed experience, age, present and expected salary.

V-536. A large manufacturing firm in the Middle West would like to get in touch with young men who are just finishing university courses in electrical or mechanical engineering, or who left their university courses to enter Army and Navy service and are now looking for employment. Good opportunities will be open for the right men in sales, engineering, design and research work. In answer please state educational training and experience.

V-537. Foreman wanted for electrical instrument testing department. Applicant should have had executive, practical and technical experience. This position is open only to a man who appreciates the value and necessity of maintaining and improving the quality of the products. In reply state age, past experience and compensation desired.

V-538. A Southern technical college has an instructorship to offer in the Electrical Engineering Department. Salary $1200. The work will consist largely of laboratory instruction.

V-539. Chief Draftsman. Man thoroughly experienced in the design of electrical measuring and protective apparatus. Married man preferred. Location Pennsylvania. In reply give detailed experience record, age and salary desired.

V-540. Electrical manufacturer in New York City has opening in its engineering department for a young man, technical graduate. Rapidly growing business in new field. Exceptional opportunities for right man.

V-541. Wanted. Design engineer experienced in modern substation and power plant layouts. Location New York City. Give details of experience and salary expected.

Electrical Assistant (male). The United States Civil Service Commission announces an open competitive examination for electrical assistant (men only) on July 23, 1919, at various places throughout the United States. Vacancy in the Signal Service at Large, War Department, San Francisco, at $1800. a year and future similar vacancies at $1500. to $1800 a year will be filled from this examination. Duties require familiarity with practical side of electricity as applied to telegraph, telephone and kindred engineering. Applicants must be 20 years old, have a common school education and at least three years' experience with telegraph or telephone company. Applicants should apply at once for Form 1312, stating title of examination, to Civil Service Commission, Washington, D. C.

Draftsmen wanted for the Panama Canal. Draftsman (electrical) at $200. to $220. a month. Must be technical school graduate with at least three years' drafting room experience and capable of handling the electrical design work on steam or hydro-electric stations and high or low tension substations. Draftsman (electrical) at $168. to $179. a month. Must have had at least two years' drafting room experience in underground power distribution and building illumination. All applicants must be in good health and physically sound, American citizens, and if foreign born must submit with their application their final certificate of naturalization or that of their father if they claim citizenship through him, which will be returned promptly. Age limits 20 to 45 years. Free steamship transportation is furnished from New York or New Orleans to the Isthmus to new appointees, salary beginning on date of sailing. Must pay own railroad fare to port of sailing. Free bachelor quarters are furnished on the Isthmus and meals can be secured at the Government hotels at about 40c. each. Yearly leave with pay up to 61 days may be allowed. Write for Form 115 and complete information from Chief of Office, The Panama Canal, Washington, D. C.

SERVICES AVAILABLE

1315. Technical graduate in electrical engineering with post graduate degree of M. S., desires change of position because of narrow field offered by present position. Three years teaching electrical subjects and three years with large engineering company on development and design work. At present holding responsible position. Married. Age 28. Salary $3000.

1316. Electrical Engineer. Technical graduate with ten years broad experience, covering construction, operation and maintenance of electrical power plants, sub-stations, lighting distribution systems and general industrial power applications. Age 30, married; highest references; available on short notice. Present salary $2400.

1317. Electrical engineering graduate, 33 years of age, desires position as signal and electrical engineer. Has had ten and one half years' experience on steam and electric railroads, including four years in position of signal engineer. At present an officer of the Signal Corps in France. Available September 1. Minimum salary $3300.

1318. Electrical Engineer, 40, married, eighteen years' experience construction, operation hydroelectric, Diesel, and gas-power plants. Present position superintendent of power in mining company South America, including hydroelectric, Diesel and gas-power plants. Available August 1. Speaks and writes Spanish. Direct letter or cable for further information: Engineer, Casilla 7556, Santiago de Chile.

1319. Electrical engineering graduate, now First Lieutenant Engineers, just returned from overseas, desires position as constructing or operating engineer. Experienced in power plant construction and operation. Can handle men. Age 26. Salary $1800.

1320. Electrical Engineer, 35, married, eight years in power, substation, transmission line design and construction. Experienced in hydroelectric power on Pacific Coast. Desires position in South America on Atlantic slope in charge of complete design and construction of hydroelectric developments. Now in Chile. Available on three months notice. Speaks Spanish. Salary $4000.

1321. Technical graduate, age 27, single, healthy, two years General Electric test, one year construction foreman, one year Second Lieutenant Signal Corps. Desires position as works electrical engineer or connection with industrial engineering firm. Salary $2500.

1322. Graduate (1919) electrical engineering, desires position with an electrical contractor or with a public service company offering opportunity for advancement. Have been employed summers along various electric lines. Age 22. Eastern location preferred.

1323. Electrical engineer, 37, married, about 18 years successful experience in mechanical and electrical work both technical and executive. Desires broader field. Qualified for a high grade position with an engineering college or firm of consulting engineers.

1324. Assistant to electrical and mechanical engineer for three years on large work in Latin American country, technical graduate, speak Spanish, age 27. Considerable experience on construction work and handling of men. Desires position with large organization. Willing to go anywhere. Salary $3000.

1325. Electrical engineer, 31, maried. Technical graduate with several years experience in central station and substation construction and maintenance, including the design and layout for reconstruction and additions, desires change offering responsible position with broader opportunities. Good executive. Minimum salary $2400.

1326. Teacher of electrical engineering. Graduate degree, middle western university. Four years teaching experience, two years practical engineering work, and some experience teaching radio. Also keenly interested in research. Age 29 years, unmarried. Salary $1800.

1327. Engineering executive, graduate electrical engineer. Extensive experience in construction and operation of electric railways and power properties, also in factory management and syndicate work. Age forty-two. Desires connection with consulting and construction firm with possible future purchase of interest or with company in which prospects are good. Salary $5000.

1328. College and technical graduate, twenty years practical experience, electrical and mechanical, involving design and construction of light and power distribution, central and substation layouts, high and low-tension underground and pole line transmission, estimating and valuation work; desires permanent connections with an established firm or industrial plant. Salary dependent on prospect. Best references.

1329. Electrical engineering graduate, with commercial and teaching experience along power machinery and central station lines, wishes position with electrical manufacturing company in engineering or sales department; or with a public utility company. Middle West preferred. Could invest a few thousand dollars in a first class going concern.

1330. A cable engineer with eight years' experience in the design, manufacture, testing and installation of all kinds of mines and cables. Age 30. Technical education. Married.

1331. Graduate electrical engineer, extensive supplemental training in advanced physics and chemistry, and ten years thoroughly practical experience wishes position as research director or engineer with manufacturing company, or with consulting engineer. Exceptionally broad experience in research, both electrical and chemical, and in engineering commercial application of developments. Experienced directing subordinates.

1332. Head of Department of electricity and telephony at a well-known correspondence school desires position as assistant professor of electrical engineering, physics or mechanical engineering. Technical graduate 1910, degree M. E., four and one-half years practical experience in electrical and mechanical engineering. In present position nearly five years. Age 34. Married. Available on one month's notice.

1333. Telephone engineer. Technical training and experience in installation, testing, inspection, maintenance and operation of complete telephone and telegraph central office plant. Complicated circuit work a specialty. Nine years' experience. Executive and administrative ability. Can engineer and supervise the installation of complete telephone plant. Minimum salary $2200. per annum.

1334. Public utility manager and engineer, experienced in operation of ice plants; recently returned from Europe, desires position. Before the war; manager four years, group of properties including city of one hundred thousand population. Particularly strong as executive and as power generation engineer; successful with public. Age 42.

1335. Graduate electrical engineer, seven years' experience, General Electric test, operation, design, construction of hydroelectric plants, appraisal and consulting; desires position with established public service corporation as operating engineer or superintendent. Married. Age 29.

1336. College engineering graduate, age 25, with about two years' experience in operation of power plant, design of electrical and mechanical appliances, and in switchboard development work, desires a position in medium sized electrical industry where chances for advancement are good. Minimum salary to start $35.00 to $40.00 per week, depending upon location. Best references.

1337. Electrical engineer, age 38, thirteen years' experience in operation and maintenance of power plants, distribution and transmission systems; two years commercial office experience; ten years with one company and five years with present company. Technical graduate. Associate A. I. E. E. Salary $3000.

1338. Power plant chief engineer with wide experience in both construction and operation of steam and hydraulic stations, desires to make change in position. Salary $3000. a year. Best of references, including present employers.

1339. Electrical engineer, married, age 32, ten years general engineering experience, development and construction, power plants, waterworks, sewerage, electrochemical copper deposition and shop production. At present in charge of industrial plant layout. Eastern location desired. Salary $3600.

1340. Technical graduate, age 27. Two years testing experience including some factory work, one year sales engineer. Desires position as sales engineer; location in Cleveland preferred.

1341. Very ambitious young man, age 24, would like position in engineering department of firm where advancement is rapid. Have had good technical electrical education and three years' experience in telephone plant maintenance, and three years in office work. Engaged at present, but available on short notice. Best references.

1342. Graduate electrical engineer, five years' experience with manufacturers as construction, industrial and sales engineer and two years field service as Captain, Engineers, U. S. Army, desires position requiring engineering and executive ability, integrity and tact. Thoroughly experienced in manufacture, operation and application of all types of electrical machinery. Highest of references. Correspondence is invited.

1343. Graduate electrical engineer. Experience: Design and manufacture of steam apparatus and devices; iron ore mining and development of property; contact method sulphuric acid plant design and construction; some chamber plant design. Pleasing personality, competent and energetic.

1344. Technical graduate, age 27, single. Associate in A. I. E. E. Desires position with electrical or manufacturing company with opportunity for advancement. Not afraid to work. Ten months testing transformers with Westinghouse Elec. & Mfg. Co. Two years chief electrician U. S. Navy. Six years electrical experience. Will be released from U. S. N. by July 20.

1345. Former Captain of Engineers, Yale graduate, 35, unmarried, with shop and business experience. Five years branch sales office manager for large electrical manufacturer. Desires executive position where engineering and sales experience and business ability will count.

1346. Hydroelectric engineer, Member A. I. E. E., experienced in designing and constructing hydroelectric power developments and high-voltage transmission, also fifteen years as manager in Spanish-American country, is open for engagement in United States or elsewhere.

1347. Electrical engineer and superintendent, technical graduate, Member A. I. E. E., seven years' experience, age 32, recently released from Army, desires position as electrical engineer of industrial plant or distribution engineer of central station. Broad experience in design, construction and operation, electrical equipment of mills and mines. Formerly electrical superintendent of plant employing approximately one hundred electricians. Salary $3000.

1348. Electrical engineer, graduate University of Wisconsin 1917, six months with large eastern firm in construction work, one year as engineer and electrical officer on submarine. Desire construction work in middle west. Available after August 1.

1349. Superintendent of nineteen years' experience both in the construction and operation of power houses, substations and high tension transmission lines. Good executive, able to handle men in large numbers. Have had large experience in purchasing. Am thirty-eight years old, single, and willing to go any place.

1350. Graduate electrical engineer 1907, age 36 years, at present with consulting engineering company. Desires to make a change. Seven years in charge of power house and substation construction for light and power company. Also considerable maintenance experience. Can give references and additional information. Salary expected $3600.

1351. Wanted, executive, engineering or sales position. Canadian, speak English and French correctly. Thirty-eight, married, self educated. Five years telegraph and telephone, operating manufacturing. Five years electrical engineering on hydro, industrial and manufacturing. Three years sales and general engineering. Five years Government electrical inspector. Location no object. Salary $4000.

1352. Mechanical and electrical engineer, unmarried; excellent executive ability; desires permanent position in China. Has recently returned from France as a Captain of Engineers. Would prefer work in the commercial field, but would consider any work for which qualified.

1353. Electrical and mechanical engineer, 27, college, desires position with an electrical manufacturing company, in capacity of designing, research, testing and development of new electric apparatus and machinery. Experienced in development, etc., of electrical apparatus, power station design and electric railway work. Available on one week's notice to present employer. References all former employers.

1354. Electrical graduate, single, testing, commercial and sales experience with large manufacturer desires position with growing concern. Available September 1. Middle West preferred.

ENGINEERING SOCIETIES LIBRARY

The library, which comprises the individual libraries of the American Institute of Electrical Engineers, the American Society of Mechanical Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Civil Engineers, and the United Engineering Society, is ocated on the thirteenth and fourteenth floors of the Engineering Societies Building. In addition to engineering works it contains general reference books on allied sciences such as Physics, Mathematics and Chemistry. The library also contains publications of practically all the engineering societies in the world as well as current and bound sets of more than 1,000 engineering periodicals in English and other languages.

In order to place the facilities of this great engineering library at the disposal of persons residing out of town, a Library Service Bureau has been established, and a staff of expert searchers and translators is prepared to cover almost any engineering topic. Charges for service are at actual cost. Ph tostat copies of prints, drawings, etc., are $0.25 per 10 x 14 inch sheet.

All communications should be made as definite as possible so that the information received may be what is desired and not include collateral matter of no interest. The time spent in searching for such collateral matter will be saved, and information sent more promptly and in mo e usable shape.

Members who may desire it will be kept informed regarding current publications on any engineering subject for a small annual fee.

The library is conducted as a free public library of reference. It is open to the public from 9 a m to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a.m. to 6 p.m.

Accessions.—(May1–May 31, 1919) Unless otherwise specified, books in this list have been presented by the publishers. The Institute does not assume respon ibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

THE AMERICAN MACHINIST SHOP NOTE BOOK:

A Collection of Articles, Written for the American Machinist by Practical Men, Covering a Wide Variety of Machine Shop Activities and Giving the Solutions of Problems that have Arisen in Machine Shops the World Over. Compiled by E. A. Suverkrop. 1st edition. N. Y., published by American Machinist, McGraw-Hill Book Co., Inc., sole selling agents. 301 pp., 223 illus., 9 x 6 in., cloth, $2.

CONTENTS: Drafting and Design; Patterns and Foundry; Forge Shop, Hardening and Tempering; Drilling Machine; Engine Lathe; The Milling Machine; Planer and Shaper; Tool Making; Die and Press Work; Gages; Grinding; Boring; Gearing; Screw Machine; Shop Tools, Appliances and Expedients.

A collection of methods for dealing with difficult or unusual machine-shop jobs, compiled from the periodical mentioned, and classified under the above headings to facilitate ready reference. The articles show methods that have been successful and are suggestive to the machinist faced by similar difficulties.

CUTTING CENTRAL STATION COSTS:

Ways by which Central Station Managers, Operating Engineers and Sales Managers are Meeting High Costs. Compiled by S. B. Williams. 1st edition, N. Y., Published by Electrical World, McGraw-Hill Book Co., Inc., sole selling agents, 1919. 322 pp., illus., 9 x 6 in., cloth. $2.

The Commercial Editor of the *Electrical World* has here collected the material contributed to that journal during the last nine months of the war, explaining methods adopted by various central stations. Economies in boiler and generating rooms, line construction and distribution methods and substation practise, commercial practise and administrative plans are discussed.

EFFICIENT RAILWAY OPERATION:

By Henry S. Haines, N. Y., The Macmillan Co., 1919. 709 pp., tables, 9 x 6 in., cloth, $4.50.

This volume is a description of the progressive development of efficiency in the operation of the railway system in the United States, as compared with similar progress in other countries, for the use of students, railway employees and general readers. Railway operation, as distinguished from administration, is the subject of the book; matters of finance, rates and labor questions are therefore not included.

A bibliography and extensive statistical tables are given in the appendixes.

ELECTRICITY AND MAGNETISM FOR ENGINEERS.

Part II. Electrostatics and Alternating Currents. By Harold Pender. 1st edition, N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1919. 221 pp., 172 illus., 9 x 6 in., cloth, $2.

Gives from an engineering point of view, a description of the more important effects commonly described as electrical and magnetic phenomena, and the application of these laws to some of the simpler problems which arise in connection with the generation, transmission and utilization of electrical phenomena. Intended for college instruction.

HANDBOOK FOR HIGHWAY ENGINEERS:

Containing Information ordinarily Used in the Design and Construction of Rural Highways. By Wilson G. Harger and Edmund A. Bonney. 3rd edit., entirely revised. N. Y., McGraw-Hill Book Co.; Lond., Hill Publishing Co., Ltd., 1919. 986 pp., illus., tables, 1 map, 7 x 4 in., flexible cloth, $4.

This handbook is a compact volume, presenting in convenient form the information ordinarily required in the field and office practise of road design and construction, and is planned to meet the requirements of both experienced and inexperienced road men.

In the present edition, approximately 350 pages of new material have been incorporated, covering mountain road location and design, camp equipment, medical notes, photography, selected soil and gravel treatment of moderate traffic roads and the recent developments of hard surface roads.

JAMES WOODHOUSE, A PIONEER IN CHEMISTRY, 1770-1809.

By Edgar F. Smith. Phila., The John C. Winston Co., 1918. 299 pp., 1 pl., 1 por., 8 x 5 in., cloth, $1.50.

Dr. Smith's account of the life and labors of James Woodhouse is a valuable contribution to the early history of chemistry in America. Woodhouse was elected Professor of chemistry at the University of Pennsylvania in 1795 and retained this connection until his death in 1809. He was an industrious and ingenious chemist, who by his work and writings did much to establish the teaching of chemistry on a sound basis and to arouse interest in the industrial applications of the science.

MARINE INSURANCE:

Its Principles and Practise. By William D. Winter. 1st edition. N.Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1919. 433 pp., 8 x 6 in., cloth, $3.50.

In this treatise, the writer presents a thorough, simple exposition of marine insurance; suited to the needs of shipping men, merchants and others who require a general knowledge of the subject. Based on a course of lectures given at New York University.

MATHEMATICS FOR ENGINEERS:

Part I. Including Elementary and Higher Algebra, Mensuration and Graphs, and Plane Trigonometry. By W. N. Rose. N. Y., E. P. Dutton & Co., (1919). 510 pp., 257 illus., 11 tables, 9 x 6 in., cloth, $5. (The Directly-Useful Technical Series).

This treatise endeavors to cover all the mathematical work needed by students and engineers in their practise, and is intended also to serve as a reference book for private study. Part I deals with the fundamental rules and processes of Algebra, Plane Trigonometry, Mensuration and Graphs. Practical applications having a direct bearing on engineering practise are added in the greater number of instances and many calculations, tables and charts designed to make the book of the greatest possible assistance to busy engineers are included.

PRACTICAL SHELL FORGING

And the Plastic Deformation of Steel and Its Heat Treatment. By Clifford O. Bower, N. Y., Longmans, Green & Co., 1919. 279 pp., 152 illus., 4 pl., 17 tables, 10 x 6 in., cloth, $10.50.

This volume, by an experienced British forge master, is a detailed account of the processes of shell manufacture, in which particular attention is given to the laws governing the plastic deformation of steel at high temperatures and the variations in its physical character to be obtained by thermal treatment. It will be useful indirectly, the author hopes, to all persons engaged in the manufacture of hydraulic forgings.

TRAINING FOR THE ELECTRIC RAILWAY BUSINESS:

Written under the supervision of T. E. Mitten by C. B. Fairchild, Jr., Philadelphia and Lond., J. B. Lippincott Co., 1919. 155 pp., 9 pl., 3 charts, 8 x 5 in., cloth, $1.50.

Explains in non-technical language the business side of electric railroading, and gives an insight into the requirements, the opportunities and the training involved in the several departments. The various engineering and transportation problems are taken up and the recruiting and management of the army of laborers needed thoroughly discussed.

TRAUTWINE:

The Civil Engineer's Pocket-Book. By John C. Trautwine. Revised by John C. Trautwine, Jr., and John C. Trautwine, 3rd. 20th edition. Phila., Trautwine Co., 1919. 1528 pp., illus., tables, 7 x 4 in., flexible cloth, $6.

The present volume represents the fourth extensive revision of this well-known work of reference since its original appearance in 1872, and the first since the nineteenth edition as published in 1909.

The present edition contains 271 more pages than the preceding one. In its preparation, about 400 pages of material have been inserted, relating principally to matters connected with railways, on which subject about 250 pages of new matter have been added. Besides this inclusion of new data, the work has been revised and brought up to date throughout.

THE TURNOVER OF FACTORY LABOR:

By Summer H. Slichter, with an introduction by John R. Commons. N. Y. and Lond., D. Appleton & Co., 1919. 460 pp., tables, 8 x 5 in., cloth, $3.00.

CONTENTS: General Analysis of the Turnover, The Cost of the Turnover, The Causes of the Turnover, and Methods of Reducing the Turnover.

The author intends his volume as a comprehensive study of methods of handling men, to supplement existing books on works management. It is founded on personal experience in large industrial plants, visits to factories, talks with employers and working men, schedules and questionnaires. As the study was begun in 1913 and most of the data were collected before the acute situation of 1916, the discussion is from the standpoint of the situation in peace times.

The book deals with manual laborers generally, except out-of-door seasonal workers.

ASSOCIATES ELECTED JUNE 25, 1919

ACKHURST, JOHN STANLEY, Apparatus & Supply Salesman, Canadian General Electric Co., Halifax, N. S.

ADAMS, C. CLIFFORD, Elec. Engineering Foreman, Western Machinery Co.; res., 133 N. 11th Ave., Phoenix, Ariz.

ALDOUS, ERNEST E., Asst. Manager, Denver Office, American Steel & Wire Co., 1st Nat'l Bank Bldg., Denver, Colo.

AMY, ERNEST V., Laboratory Assistant, New York Edison Co., 92 Vandam St.; res., 48 West 70th St., New York, N. Y.

ANTHONY, ALFRED W., JR. Asst. Electrical Engineer, Edison Electric Ill. Co. of Brockton, 89 Highland St., Brockton, Mass.

ARCHER, HARRY, Erecting Engineer, General Electric Co., 609 Colman Bldg., Seattle, Wash.

ARMINGTON, RALPH L., Asst. Engineer, Boston & Maine R. R., Boston; res., 63 Princeton St., Medford, Mass.

ATKINSON, JOHN EARL, Machinery Application Engineer, Westinghouse Elec. & Mfg. Co., 1400 Alaska Bldg., Seattle, Wash.

BACON, VAUGHAN ROBERT, Partner, Bacon & Strahmann, Woodman of the World Bldg., Omaha, Neb.

BANDORF, WALTER, Sales Engineer, Westinghouse Elec. & Mfg. Co., 121 E. Baltimore St., Baltimore, Md.

BARBER, SAMUEL HILLIARD, Tester of Motors & Generators, Diehl Mfg. Co.; res., 1024 E. Jersey St., Elizabeth, N. J.

BARKER, ROBERT J., Local Representative, Westinghouse Elec. & Mfg. Co., 619 C. of C. Bldg., Rochester, N. Y.

*BARRY, ROBERT LEE, Sales Engineer, Goodman Mfg. Co.; res., 3722 Lueders Ave., Cincinnati, Ohio.

BARTH, ERNEST ALBERT, Ensign, (Electrical) U. S. N. R. F., 15th Regiment, Great Lakes Naval Training Station, Great Lakes, Ill.

*BASSETT, HERBERT B., Electrical Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., Clover Club, Edgwood Park, Pittsburgh, Pa.

BECK, ROY J., Electrical Engineer, Century Electric Co., 6031 Westminster Place, St. Louis, Mo.

BEKKU, SADATOSHI, Engineer, Electrotechnical Laboratory, Imperial Government, Tokyo, Japan.

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Robertson, Elgin B., Designing Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 7470 McClure Ave., Swissvale, Pa.

Robinson, Goldsborough, Electrical Engineer with The Electric Controller & Mfg. Go., Cleveland, Ohio.

Roe, Francis S., Service Dept., Westinghouse Elec. & Mfg. Co.; res., 551 South Graham St., E. Pittsburgh, Pa.

Rogers, Foy O., Patrol & Service Maintenance Foreman, Hydro-Electric Power Plant, Dieringer, Wash.

Romaine, William R., Jr., Tech. Assistant to Manager, Seth Thomas Clock Co., 19 W. 44th St., New York, N. Y.

Roys, Orzo, Jr., Supt., Electrical Dept., International Paper Co.; res., 22 Shippey Ave., Glens Falls, N. Y.

Ruble, L. S., Salesman, North Coast Electric Co., 329 Everett St., Portland, Oregon.

***Rundle Lewis P.,** Engineering & Drafting, Can. Crocker-Wheeler Co. Ltd.; res., 75 Lowell Ave., St. Catharines, Ont.

Russell, Frederick G., Deputy Supt., Mill Div., Tata Hydro-Electric Power Supply Co. Ltd., Bombay, India.

Russell, Herbert Abbott, Foreman Draftsman, Engineering Dept., Toronto Hydro-Electric System, Toronto, Ont.

Russell, W. Earl, Asst. Engineer, Hydro-Electric Power Commission, 190 University Ave., Toronto, Ont.

Sanderson, Wiley D., Elec. Engineering Dept., The Detroit Edison Co.; res., 489 Hazelwood Ave., Detroit, Mich.

Sandin, Jerome, Electrical Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., Clover Club, Edgwood Park, Pittsburgh, Pa.

***Sappington, R. Dorsey,** Inspector, Canadian Niagara Power Co., Niagara Falls, Ont.; res., 25 Mentz Apts., Niagara Falls, N. Y.

Schermerhorn, H. Louis, General Electric Co., Schenectady; res., Scotia, N. Y.

Schick, Clarence S., Electrician, Erie Forge & Steel Co., 509 Reed St., Erie, Pa.

Schoonmaker, Lucas E., Captain, C. A. C., U. S. A.; res., 45 Clarendon Place, Orange, N. J.

Scoville, Gilbert L., Engineering Dept., Pacific Tel. & Tel. Co., 620 Sheldon Bldg., San Francisco, Cal.

Scranton, Kenneth L., Electrical Draftsman, Northeast Elec. Co.; res., 243 Frost Ave., Rochester, N. Y.

Seeley, Walter J., Shipyard Work, Groton Iron Works, 140 Ocean Ave., New London, Conn.

Sharland, George Albert, Chief Electrician, Minnesota By-Product Coke Co.; res., 2176 Scudder St., St. Paul, Minn.

Shaw, Heber Ernest, Transformer Div., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 1427 Cresson St., Wilkinsburg, Pa.

Shaw, James S., Supt. of Construction, Union Electric Light & Power Co., 6441 Page Ave., St. Louis, Mo.

Sheldon, Malcolm H., Erecting Engineer, McMyler Interstate Co., Bedford, Ohio; res., 216 Ann St., Athens, Pa.

Sheridan, Frank J., Dept. Chief, Inspection Branch, Western Electric Co., Hawthorne; res., 126 N. Taylor Ave., Oak Park, Ill.

Sherwood, Louis M., Power Engineer, Consolidated Gas & Elec. Co., Lexington Bldg., Baltimore, Md.

Shuck, Gordon Russell, Instructor of Elec. Engg., Univ. of Washington; res., 311 E. 55th St., Seattle, Wash.

Shull, Frederick G., Sales Engineer, Aluminum Co. of America, 131 State St., Boston, Mass.

Sibley, Edwin Francis, Chief Electrician, Ensign, Engineer, U. S. A.; res., 128 Derby Ave., New Haven, Conn.

Simpson, John, Instructor in Electricity, Central Technical School; res., 79 Auburn Ave., Toronto, Ont.

Singleton, Lester De Lozier, Testing Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 911 North Avenue, Wilkinsburg, Pa.

Skinner, Benjamin H., Telephone Switchboard Methods Engineer, Western Electric Co., Inc., Chicago; res., 3443 Maple Ave., Berwyn, Ill.

Smith, Daniel O., Supt., Jesup Light & Water Works, Jesup, Ga.

Smith Ernest A., Electrical Foreman, Inspiration Cons. Copper Co., Miami, Arizona.

Smith, Howard J., Inspector, Elec. Headlight Equipment, B. &. O. R. R. Co.; res., 240 Jefferson St., N. S., Pittsburgh, Pa.

Smith, James J., Engineer, Transformer Dept., General Electric Co., Pittsfield, Mass.

Smith, John E., Electrical Tester, Diehl Mfg. Co., Elizabeth, N. J.

Smith, N. B., General Construction Foreman, West Penn Power Co., Connellsville, Pa.

Smith, William E., Asst. Elec. Engineer, Chevrolet Motor Co., Tarrytown; res., 303 E. 40th St., Brooklyn, N. Y.

Snow, Leo D., Foreman of Testing Laboratory, Puget Sound Traction, Light & Power Co., Seattle, Wash.

Spencer, Thomas James, Puget Sound Traction, Light & Power Co., Dieringer, Wash.

***Spiller, P.**, Electrical Draftsman, Federal Shipbuilding Co., Kearny, N. J.; res., 891 Jefferson Ave., Brooklyn, N. Y.

Spiruta, Frank J., Designer, B. F. Goodrich Co., Akron, Ohio.

Stangebye, Harold, The Steel &Tube Company of America, Indiana Harbor, Ind.; res., 7352 Eberhart Ave., Chicago, Ill.

Stephens, John G., First Engineer, Lake Coleridge Power Station, Whakamatau, Christchurch, N. Z.

Stephenson, Orel Penn, Testing Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 841 Holland Ave., Wilkinsburg, Pa.

Streiff, Albrecht, Operator, Northwest Electric Co., Hillsdale, Oregon.

Strieby, Malcolm Staunton, Central Office Man, Bell Telephone Co. of Pa., Pittsburgh; res., 1356 Fifth Ave., Newkensington, Pa.

Stull, Robert J., Testing & Regulating Attendant, Western Union Tel. Co.; res., 3548 Geary St., San Francisco, Cal.

Sturges, Hugo B., Department Electrical Inspector, City of Portland; res., 719 East 61st St. North, Portland, Ore.

Swenson, George W., Electrical Engineering Dept., Univ. of Minnesota, Minneapolis, Minn.

Taketa, Shiro, Elec.Draftsman,Power Dept., The Philadelphia Electric Co.; res., 3420 Somsom St., Philadelphia, Pa.

Taylor, Albert Hoyt, Lieut-Comm., U. S. N. R. F., Naval Radio Laboratory, Aircraft Div., Bureau of Standards, Washington, D. C.

Taylor, Harry B., Chief Clerk & General Foreman, Detroit Edison Co., 18 Washington Blvd., Detroit, Mich.

Teague, W. I., Division Supt. of Plant, The Pacific Tel. & Tel. Co., 835 Howard St., San Francisco, Cal.

Thompson, Benjamin F., Telephone Engineer, Baltimore & Ohio R. R., Baltimore; res., Oakdale Ave.,Arlington, Md.

Thompson, Earl V., Elec. Engineer, Gold Medal Camp Furniture Mfg. Co.; res., 1646 Thurston Ave., Racine, Wis, THOMPSON, HENRY C., Electrical Engineer, Westinghouse Elec. & Mfg. Co., St. Louis, Mo.

THRASHER, WILLIAM ALEXANDER, Chief Electrician, Dominion Shipbuilding Co.; res., 258 Roxton Road, Toronto, Ont.

TIBBITTS, FAYETTE A., Sales Engineer, Western Electric Co., Boston; res., 10 Lincoln St., Arlington, Mass.

TIGERMAN, JOSEPH H., Switchboard Engineer, The Pacific Tel. & Tel. Co., 835 Howard St., San Francisco, Cal.

TOBEY, A. A.,Electrical Contractor, 103 W. Park, Portland, Oregon.

TOBIAS, Abraham, Mechanical Engr., Office of Supervising Architect, Treasury Dept., 232 6th St., S. E., Washington, D. C.

TREFFINGER, HARRY H., Foreman, Electrical Dept., Baltimore & Ohio R. R.; res., 706 S. Ellwood Ave., Baltimore, Md.

TURNER, W. D., Electrician, Colorado Fuel & Iron Co.; res., 2130 Pine St., Pueblo, Colo.

TUTTLE, ALBERT EDWARD, Lieut., U.S. N. R. F., Acting Inspector of Engineering Materials, U. S. N.; res., 17 Gramercy Park, New York, N. Y.

ULTSCH, HENRY, DRAUGHTSMAN, T. E. Murray, 124 E. 15th St., New York, N. Y.

VAN DER BENT, WALTER SIDNEY, Sprague Electric Works of General Electric Co., Bloomfield, N. J.; res., 548 W. 162nd St., New York, N. Y.

VANDERSLUIS, WARREN M., Signal Engineer, Illinois Central R. R., 900 Central Station, Chicago, Ill.

VAN EMDEN, AARON L., Electrical Asst., Boston Elevated R. R., Boston; res., 30 Fabyan St., Dorchester, Mass.

VAN OSTEN, JAMES WRIGHT, Captain, Signal Corps, U. S. A., 8-10 Bridge St., New York, N. Y.

VEEDER, WILLIAM J. G., Engineering Dept., General Electric Co., Chicago, Ill.

VON HEIMBURG, FRED H., Consulting Engg. Dept., General Electric Co.; res., 707 South Ave., Schenectady, N. Y.

WALLACE, J., Central Office Engineer, Pacific Tel. & Tel. Co.; res., 453 34th Ave., San Francisco, Cal.

WALLACE, JAMES, Draughtsman, Hydro-Electric Power Commission of Ontario; res., 115 Marchmont Road, Toronto, Ont.

WALSH, WALTER J., Operator, Butte Elec. Railway Co., 225 Curtis St., Butte, Mont.

WARREN, WILLIAM HENRY, Transmission Inspector, The Pacific Tel. & Tel. Co.; res., 657 O'Farrell St., San Francisco, Cal.

WARRING, ROYAL CORBETT, Engineer, Bay State Street Railway Co., Boston; res., 124 Jewett St., Newton, Mass.

WARRIS, JOHN FORD, Lieut. (j.g.), U.S. N., Executive Officer & Electrical Officer, U. S. S. S.-33, Union Iron Works, San Francisco, Cal.

WASHINGTON, LEE S., Salesman, Westinghouse Elec. & Mfg. Co., 314 N. Broadway, St. Louis, Mo.

WAUCHOPE, JAY MAXWELL, Chief Electrician, International Smelting Co., Tooele, Utah.

WEBB, ROBERT T., Engineer, Wagner Electric Mfg. Co.; res., 5259 Vernon Ave., St. Louis, Mo.

WELLS, ARCHIBALD REID, Meter Construction Engineer, Hydro-Electric Power Commission, 8 Strachan Ave., Toronto, Ont.

WENTWORTH, ALFRED S., Commercial Engineer, Westinghouse Elec. & Mfg. Co., 121 E. Baltimore St., Baltimore, Md.

WHITE, WILFRED A., Engineer, North Coast Power Co., 441 Pittock Block, Portland, Ore.

WILE, SAMUEL GILLMORE, Electrical Constructing, Hydro-Electric Power Commission of Ontario; res., 109 Campbil Ave., Toronto, Ont.

WILLS, J. C., Operating Dept., Hydro-Electric Power Commission, 190 University Avenue, Toronto, Ont.

WILSON, JAMES GUY, Electrician, West Penn Power Co., Dunbar, Pa.

Wilson, Norton Parker, District Service Manager, Westinghouse Elec. & Mfg. Co.; res., 1511-11th Ave. West, Seattle. Wash.

Wohlgemuth, Melville J., Switchboard Engg. Dept., Westinghouse Elec. & Mfg. Co.; res., 5405 Black St., Pittsburgh, Pa.

Wright, Earl L., Transformer Sales Dept., General Electric Co., Pittsfield, Mass.

Wright, Noble A., Electrical Engineer, The Schaw Batcher Co. Pipe Works, So. San Francisco; res., 438-26th St., San Francisco, Cal.

Wyer, George R., Manager, Pump & Electrical Depts, Canadian Fairbanks Morse Co. Ltd., 26–28 Front St. W., Toronto, Ont.

*Former Enrolled Students.

Total 358

ASSOCIATES RE-ELECTED JUNE 25, 1919

Barber, H. C., District Sales Manager, Standard Underground Cable Co., 201 C. P. R. Bldg., Toronto, Ont.

Bothwell, Clarence C., Sales Manager, Canadian Laco-PhillipsCompany, C. P. R. Bldg., Toronto, Ont.

Crowley, John W., Salesman, Westinghouse Elec. & Mfg. Co., 121 E. Baltimore St., Baltimore, Md.

Dawson, Arthur W., Supt., Michigan Northern Power Co., Sault Ste. Marie, Mich.

Jones, Joseph Stansbury, Engineer, Charles Cory & Son, Inc., 290 Hudson St., New York, N. Y.

Schmeisser, Ernest Gail, Secy. & Treas.,Baltimore Oil Engine Co., 1700 David Whitney Bldg., Detroit, Mich.

Sears, Georg G., Supt., White River Division, Puget Sound Traction, Light & Power Co., Dieringer, Wash.

Walker, Edwin M., General Manager, Terre Haute, Indianapolis & Eastern Traction Co., Tribune Bldg., Terre Haute, Ind.

Young, Walter E., Asst. Manager, Apparatus Sales Dept., Canadian General Electric Co., 212 King St., West, Toronto, Ont.

MEMBERS ELECTED JUNE 25, 1919

***Adams, Charles Clyde**, Switchboard Specialist, General Electric Co., 1016 Monadnock Block, Chicago, Ill.

Adams, William Charles, Chief Engineer, Northern Electric Co., Ltd., Montreal, Quebec.

Bretch, Edw., President, Advance Electric Co., 20 N. Commercial St., St. Louis, Mo.

Burton, Harry James, Supt. of Construction Dept., Consumers Power Co.; res., 238 Oak Ridge Drive, Jackson, Mich.

Cady, Walter G., Prof. of Physics, Wesleyan University; res., 49 High St., Middletown, Conn.

Cutts, Frederick, Local Manager, General Electric Co.; res., 278 Canner St., New Haven, Conn.

Douglass, William Edwin, Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Du Bois, Charles G., Vice-President, Western Electric Co., 195 Broadway, New York, N. Y.

Edsall, William S., Publicity Supt., Sperry Gyroscope Co.; res., 94 South Oxford St., Brooklyn, N. Y.

Howes, Franklin J., Engineer in Charge, Engg. Dept., Rochester Railways & Light Co., 34 N. Clinton Ave., Rochester, N. Y.

Ink, John B., Electrical Engineer, Stone & Webster Boston; res., 186 Elmwood Ave., Wollaston, Mass.

Kellam, Clark Jacob, General Meter Inspector, Public Service Electric Co., 80 Park Place, Newark, N. J.

Kolster, Frederick A., Physicist, U. S. Bureau of Standards, Washington, D. C.

Orr, Robert Ellis, Asst. Engineer, Pacific Electric Ry. Co., 694 Pacific Elec. Bldg., Los Angeles, Cal.

Sheperd, Russell R., Electrical Supt., Steel & Tube Co. of America, Indiana Harbor, Ind.

Taylor, Edgar C., Asst. Supt., Electric Distribution, Los Angeles Gas & Electric Corp.; res., 807 West 49th St., Los Angeles, Cal.

Templin, John Richard, Consulting Electrical Engineer, Christchurch, New Zealand.

Tighe, Lawrence G., Gen. Supt., Production & Distribution, The Northern Ohio Traction & Light Co., Akron, Ohio.

FELLOW ELECTED JUNE 25, 1919

Webster, Arthur Gordon, Prof. of Physics, Director of Dept., Clark University; res., 66 West St., Worcester, Mass.

TRANSFERRED TO GRADE OF FELLOW JUNE 25, 1919

Bodler, Oscar W., Electrical Engineer, Eastman Kodak Co., Rochester, N.Y.

Squier, George O., Major General, Chief Signal Officer, War Department, Washington, D. C.

TRANSFERRED TO GRADE OF MEMBER, JUNE 25, 1919

Borden, Perry A., Instrument Engineer, Hydroelectric Laboratories, Toronto, Ont.

Brooks, Henry W., National Tractor Co., Cedar Rapids, Iowa

Brooks, Herbert B., Physicist, Bureau of Standards, Washington, D. C.

Coors, William F., Sales Engineer, General Electric Co., Butte, Mont.

Ewart, Frank R., Construction Engineer, Ewart & Jacob, Toronto, Ont.

Holcombe, Ernest S., Electrical Construction Engineer, Interborough Rapid Transit Co., New York, N. Y.

Josephs, Lyman C., Jr., Engineer, International Motor Co., New York, N. Y.

Mullergren, Arthur L., Sec's & Treasurer, Benham Engineering Co., Oklahoma City, Okla.

Tibbals, Emerson C., Electrical Engineer, Atlantic Loading Co., New York, N. Y.

Westbrook, Francis A., Engineering Dept., Habirshaw Electric Cable Co., New York, N. Y.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its regular monthly meeting, held on June 16, 1919, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

Galusha, Don L., Dwight P. Robinson & Co. Inc., New York, N. Y.

Mathey, E. D., Electrical Engineer, Air Nitrates Corp.; Electrical Engineer, American Cyanamid Co., New York, N. Y.

To Grade of Member

Alden, Vern E., Asst. to General Superintendent, Consolidated Gas Electric Light & Power Co., Baltimore, Md.

Gaillard, Capt. David St. Pierre, Executive Asst. to Chief of Nitrate Div., Ordnance Dept., U. S. A., Washington, D. C.

Herault, P. C., Supt. Transmission, Georgia Railway & Power Co., Atlanta, Ga.

Hutchinson, Lieut. George E., U. S. N. R. F., New York, N. Y.

Jones, Joseph S., Engineer, Charles Cory & Son, Inc., New York, N. Y.

Joy, William M., Chief of Electrical Design, Electric Bond & Share Co., New York, N. Y.

Kohlhaas, Herman T., Head of Apparatus Analysis Div., Engg. Dept., Western Electric Co., New York, N.Y.

Le Tourneau, Edward H., Electrical Engineer, Portland Railway, Light & Power Co., Portland, Ore.

Maddocks, William S., Head of Electrical Engineering Dept., Lockwood Greene & Co., Boston, Mass.

Mainland, James, Chief Engineer, Washington & Old Dominion Railway, Washington, D.C.

Siegfried, Joseph H., Supt. of Power, Pacific Power & Light Co., Pasco, Wash.

Sorsby, Paul C., Engineering Dept., General Electric Co., Atlanta, Ga.

Wakeman, Henry R., Supt. of Distribution, Portland Railway, Light & Power Co., Portland, Ore.

Wright, Walter F., Eugene F. Phillips Electrical Works Ltd., Toronto, Ont.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before July 31, 1919.

Arnois, C., Lynn, Mass.
Arnold, A. E., Pontiac, Mich.
Augustine, R. W., Chicago, Ill.
Avins, N., Elizabethport, N. J.
Berger, P., Chicago, Ill.
Binion, W. H., Rochester, N. Y.
Bond, J. M., New York, N. Y.
Bonner, J. S., Nashville, Tenn.
Broadwell, W. E., Nashville, Tenn.
Burleen, O., Hoboken, N. J.
Burt, R. C., Schenectady, N. Y.
Catapano, F., New York, N. Y.
Catlett, R. L., Carneys Point, N. J.
Cookingham, E. H., Spokane, Wash.
Cottrell, L. E., Port Newark, N. J.
Cunerty, T. J., New York, N. Y.
De Lapp, C. A., Kearney, N. J.
Demmert, W. C., New York, N. Y.
Ellis, A. L., (Fellow), Lynn, Mass.
Fearing, J. L., Washington, D. C.
Flood, A. A., Rochester, N. Y.
Frost, H. H., Chicago, Ill.
Gift, F. A., San Francisco, Cal.
Gillespie, L. R., Rochester, N. Y.
Gollos, A., Chicago, Ill.
Goudy, M. P., Salt Lake City, Utah
Green, J. G., Hazard, Ky.
Gross, W. C., Nashville, Tenn.
Guterman, H., New York, N. Y.
Hakanson, J., New York, N. Y.
Hamilton, W. S. H., Schenectady, N. Y.
Hart, M., (Fellow), New Orleans, La.
Hopkins, R. A., Los Angeles, Cal.
Huling, W. H., Newburgh, N. Y.
Kasahara, K., New York, N. Y.
Klinefelter, L. M., Norfolk, Va.
Kramer, A. W., Chicago, Ill.
Lankford, E. A., Boone, Ia.
Laube, O. T., Chicago, Ill.
Lauer, H., Hoboken, N. J.
Livermore, H. W., Boston, Mass.
Locke, G. A., New York, N. Y.
Logan, H., New York, N. Y.
Ludden, H. J., San Juan, Texas
Malone, J. E., New York, N. Y.
Moreton, F. E., Schenectady, N. Y.
Morris, J. M., Los Angeles, Cal.
Mullins, R. J., (Member), Eagle Grove, Ia.
Nevatt, A. E., Pueblo, Colo.
Perry, A. C., Middletown, Ohio.
Poulterer, W. T., (Member), Philadelphia, Pa.
Priddle, W. H., Toronto, Ont.
Purple, O. T., Newark Valley, N. Y.
Pyster, J. N., Perth Amboy, N. J.
Rees, J. B., Nashville, Tenn.
Roe, F. L., Wauwatosa, Wis.
Rogers, F. P., Charleston, S. C.
Ryan, F. M., Seattle, Wash.
Sauer, L. B., Chicago, Ill.
Shapiro, H., New York, N. Y.
Shaw, A. H., Surf Inlet, B. C.
Shull, W. G., Chicago, Ill.
Soengen, G. W., (Member), St. Louis, Mo.
Sparks, C., Chicago, Ill.
Starkey, F. C., Port Clinton, Ohio.
Stavert, R. E., Peterboro, Ont.
Thaxton, G. W., Ensley, Ala.
Thomason, J. J., Texarkana, Texas.
Tokarske, J. T., Pueblo, Colo.
Tone, R. W., New Haven, Conn.

Visser, C. G., Schenectady, N. Y.
Weber, W. A., St. Louis, Mo.
Whitaker, J. D., Chicago, Ill.
White, C. E., St. Louis, Mo.
Wood, O. D., Pittsfield, Mass.
Wooton, W. L., New York, N. Y.
Total 76

Foreign Applications

Abren, C. A., S. Paulo, Brazil, S. A.
Bachs, J., Barcelona, Spain
Conwell, A. L., Orota, Peru, S. A.
Duraiswamy, C. S., Assam, India.
Klein, J. F., Gatun, C. Z.
Lasnier, G., Montevideo, Uruguay, S.A.
Lauper, F. A., (Member), Huddersfield, Eng.
Liminana, M., Barcelona, Spain
Maluguer, J., Barcelona, Spain.
McCorkle, P. C., La Fundicion, Peru, S. A.
Padua, A., deM., (Member), Carmo do Rio, Brazil.
Tajima, B., Tokyo, Japan.
Whittick, R. B., Manchester, Eng.
Total 13

STUDENTS ENROLLED JUNE 25, 1919

10392	McDermott, E., Stevens Inst.
10393	Skerrett, E. M., Jr., Univ. of Pa.
10394	Roberts, F. E., Tri-State Coll.
10395	Brussell, J. R., Johns Hopkins Univ.
10396	Barnes, D. M., Univ. of Minn.
10397	Williams, T. B., Ga. School of Tech.
10398	Clarke, E., Mass. Inst. of Tech.
10399	Alverson, C. T., Univ. of Pittsburgh
10400	Charny, A. L., Univ. of Penn.
10401	McGee, R. L., Clemson Coll.
10402	Schultz, H. G., Kansas State Agr. Coll.
10403	Foreman, W. T., Kansas State Agr. Coll.
10404	Ladwig, W. J., Univ. of Wis.
10405	Spence, P. Q., Columbia Univ.
10406	O'Leary, J. J., Clemson Coll.
10407	Bloser, W. C., Penn. State Coll.
10408	Donovan, McK., Univ. of Wash.
10409	Greenhut, F. W., Brooklyn Poly. Inst.
10410	Wyckoff, R. D., Mich. Agr. Coll.
10411	Ringland, S. G., N. Y. Elec. School.
10412	Skooglund, C. M., Penn. State Coll.
10413	Sprague, C. H., Penn. State Coll.
10414	Grisell, F. E., Casino Tech. Night School.
10415	Nicholson, C. J., Catholic Univ. of America
10416	Martin, W. L., Ohio State Univ.
10417	Hoover, J. P., Drexel Inst.
10418	Davidson, E. Y., Jr., Carnegie Inst. of Tech.
10419	Gaugler, J. R., Carnegie Inst. of Tech.
10420	Nordfeldt, H. C., Carnegie Inst. of Tech.
10421	Tjiattas, A. C., Carnegie Inst. of Tech.
10422	Ross, J. L., Carnegie Inst. of Tech.
10423	Allen, A. F., Clarkson Coll. of Tech.
10424	Howie, J. L., Jr., Crane Junior Coll.
10425	Grimes, D., Univ. of Minn.
10426	Duncan, G. R., Univ. of Minn.
10427	Wood, C. O., Purdue Univ.
10428	Getz, E. L., Catholic Univ. of America
10429	Reid, H. J. E., Worcester Poly. Inst.
10430	Parsell, L. B., Purdue Univ.
10431	Mirick, H. L., Worcester Poly. Inst.
10432	Engelland, E. F., Univ. of Ill.
10433	Atkinson, H. G., Stevens Inst. of Tech.
10434	Clarke, D. B., Worcester Poly. Inst.
10435	Heckerman, W., Cooper Union
10436	Craig, S. A., Purdue Univ.
10437	Bowersock, W., Univ. of Ill.
10438	Lockett, H. E., Ohio State Univ.
10439	Driscoll, E. J., Brooklyn Poly. Inst.

Total 48

PERSONAL

Philander Betts who was commissioned Major, Engineer Reserve Corps in February 1917 and promoted to the rank of Lieut. Colonel in March 1918 received his honorable discharge from the Army on May 31, 1919. Col. Betts was detailed to the Cantonment Division, Quartermaster Dept. which later became the Construction Division of the Army. During the last few months of his service he was engaged in writing the history and compiling the historical records of all War Dept. construction made necessary in this country in connection with the war.

G. Francis Gray has returned to civilian life and is now connected with the Engineering Dept., National Aniline and Chemical Co., 21 Burling Slip, N. Y. City. While in Government service Mr. Gray had charge for a year and a half of the radio development work being done for the Signal Corps by various manufacturers and commercial laboratories.

A. D. Rickenbacher has resigned his position with the City Post Office, Washington, D. C., and is now connected with the Washington Section of the Pullman Car Lines.

Charles E. Burgoon has completed his work with the Air Nitrates Corporation, N. Y., and Muscle Shoals, Ala., and accepted a position of Senior Examiner in the Cancellation Dept. of the Emergency Fleet Corporation, Philadelphia, Pa.

C. F. Elwell, Consulting Radio Engineer, has been awarded the Cross of the Knight of the Crown of Italy on the proposal of the Minister of Marine. Mr. Elwell erected and equipped the wireless station at Rome direotly connecting Italy and the United States, as well as stations at Lyons, Nantes, Eiffel Tower and Salonica.

W. D. Weaver, now retired and to whom a memorial tablet was dedicated at the Annual Meeting of the Institute on May 16, was awarded on June 18 the honorary degree of LL.D. by his first Alma Mater, the University of Kentucky at Lexington, Ky.

L. W. W. Morrow who has been at Yale on leave of absence from the University of Oklahoma during the past year is retained at Yale as Assistant Professor of Electrical Engineering. Professor Morrow was in charge of one of the divisions of the Signals Corps Training School for Officer Candidates while it was active. When at the University of Oklahoma Professor Morrow was Director of the School of Engineering and took an active interest in public utilities of the State particularly in connection with engineering and valuation matters.

G. F. Wittig has been made Assistant Professor of Electrical Engineering in the Sheffield Scientific School of Yale University. He has been at Yale during the past year, first in connection with the Signal Corps Training School for Officer candidates and after its disbanding has been a member of the Physics Department. Professor Wittig was associated for a time with the Westinghouse, Church, Kerr Company and was for several years head of the Department of Electrical Engineering and Physics at the University of Alabama and was later Assistant Professor at the University of Pennsylvania.

Professor A. P. Little, formerly of the Bureau of Standards, who came to Yale during the past year in connection with the Signal Corps Training School for Officer Candidates has been appointed Professor of Electrical Engineering in the Colorado School of Mines.

George W. McIver, Jr., who was relieved from duty with the U. S. Army on May 10 is now affiliated with Robertson & Co., 54 Wall St., New York in charge of their Export Machinery Dept. Mr. McIver was commissioned Captain of Engineers Sept. 25, 1917 and served from May 10, 1918 until after the armistice with the 37th Electrical and Mechanical Regiment. He was then assigned to the American Peace Commission to evaluate war damages to industries. Previous to entering the army Mr. McIver was General Supt. of the Wisconsin-Minnesota Light and Power Co.

Frederick Krug, Assistant Superintendent, Electrical Dept., N. Y. & Honduras Rosario Mining Co., was married on Thursday, June 19, 1919 to Doretha Krumwiede of Brooklyn, N. Y. Mr. Krug will return with his bride to San Juancito, Honduras, Central America.

George Ellery Hale, Director of Mount Wilson Observatory and Foreign Secretary of the National Academy of Sciences has received the unusual honor of election as Associe Etranger, Academie des Sciences, Institute de France. This distinction has been held previously by but two Americans.

The National Research Council upon the presentation and acceptance of Dr. Hale's resignation as its Chairman and the election of James R. Angell as his successor, created and bestowed in perpetuity upon Dr. Hale the title of Honorary Chairman in recognition of his services to the National Research Council and to Science and Research.

OBITUARY

Captain Stuart Thomson of whose death a brief notice was inserted in the May Proceedings passed away on March 23, 1919 from the effects of bronchitis followed by double pneumonia. Capt. Thomson, son of Dr Elihu Thomson was born in Lynn' Mass., August 13, 1886. He graduated with highest honors from Harvard in 1908 and in 1909 from M. I. T. where he specialized in Industrial Chemistry and Electrochemical Engineering. He then entered the employ of the G. E. Co. in the Research Laboratory, first at Lynn and then at Schenectady, where he later entered the Consulting Engineering Dept. During the early months of the war as a civilian he worked on many war problems for the G. E. Co., was later loaned by them to Research Laboratory of the Bureau of Mines and finally received his appointment as First Lieutenant, Chemical Warfare Service, Nov. 27, 1917. Because of his unusual ability in solution of new problems he was transferred to the Aircraft Armament Section of the Ordnance Dept. working chiefly on the design and production of "Drop Bombs." In October 1918 he was promoted to the rank of Captain. He was retained in the service until March 1919. His strenuous devotion to duty so sapped his vitality, that he became an easy victim to pneumonia. Capt. Thomson who became an Associate in the A. I. E. E. in 1912 is survived by his wife, an infant son, his father Prof. Elihu Thomson and three brothers.

Alexander C. Thompson who enlisted in 1915 with the 1st Australian Flying Squadron as an Air Mechanic and served with them until the Armistice was signed, died of pneumonia two days before arriving at his home in Australia. Corporal Thompson who was mentioned in dispatches for excellent work was a graduate of Victoria University, Manchester, England and had served in Testing Dept. of the Canadian G. E. Co. He was elected an Associate in the A. I. E. E. in 1914.

Walter S. Garvey died in Minneapolis on April 26, 1919 following an illness of more than a year. Mr. Garvey graduated from the University of Minnesota in 1916, then accepting a position with the Westinghouse Elec. & Mfg. Co. in their Duluth office as Sales Engineer. He was elected an Associate in the Institute in 1918.

CHARLES E. KNOX died on the evening of June 1, 1919. Mr. Knox, who was a consulting engineer of prominence in New York City was elected an Associate in the Institute in 1899 and transfered to the grade of Fellow in 1913.

J. W. BARD died on December 13, 1918 as a result of double pneumonia following an attack of influenza. Mr. Bard at the time of his death was Chief Engineer of the Sangamo Electric Company. He graduated as an Electrical Engineer from the University of Illinois in 1906, then spending a year in Laboratory of the Western Electric Company followed by four years with the Peoria Gas and Electric Company as meter superintendent. In 1911 he entered the employ of the Sangamo Co. as Electrical Engineer later becoming Chief Engineer. Mr. Bard was elected an Associate in the Institute in 1908 and transfered to Member grade in 1913.

ADDRESSES WANTED

Any reader knowing the present address of any of the following members is requested to communicate with the Secretary at 33 West 39th Street.

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A. B. McCollum,
(former address)
4030 Lindell Blvd.,
St. Louis, Mo.

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*A complete list of the officers, committees and representatives of the Institute will be found in the June, 1919, issue of the Proceedings.

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PROCEEDINGS

OF THE

American Institute of Electrical Engineers

Vol. XXXVIII
Number 8

AUGUST, 1919

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TABLE OF CONTENTS

Section I.—Institute Affairs

Pacific Coast Convention 297
Future A. I. E. E. Meetings 297
Fifth National Exposition of Chemical Industries 297
Engineering Council:
Reports of the National Service Committee 298
Status of Water Power Legislation 298
Payment of Mileage to Engineer Officers 298
Past Section Meetings 299
Engineering Service Bulletin 300
Engineering Societies Library 304
Applications for Election 307
Recommended for Transfer 308
Personal 308
Obituary 308

Section II.—Papers and Reports

Order and Amplitude of Harmonics in Voltage Wave Forms with Indicating Instruments. By Leslie F. Curtis, Los Angeles, Cal., September 18–20, 1919 947
Theory of Probabilities Applied to Failures of Suspension Insulators. By L. M. Klauber, Los Angeles, Cal., September 18–20, 1919 959
Some Problems in the Operation of Power Plants in Parallel. By E. C. Stone, Pittsburgh, Pa., February 11, 1919 973
Predetermination of Synchronous Phase-Modifier Performance. By Hubert V. Carpenter, Los Angeles, Cal., September 18–20, 1919 997
Grounded Neutral Transmission Line. By W. E. Richards, Lake Placid Club, N. Y., June 24, 1919 1006

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GEORGE R. METCALFE, Editor.

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American Institute of Electrical Engineers

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PROCEEDINGS

Vol. XXXVIII AUGUST, 1919 Number 8

PACIFIC COAST CONVENTION

The Pacific Coast Convention of the Institute which has been announced to take place in Los Angeles, Cal., September 18-20, 1919, will be held under the auspices of the local section, and Vice-president John B. Fisken, of Spokane, Wash. has accepted an invitation to preside at the convention sessions.

The program is not yet completed, but contains the following list of technical papers; three of which are published in Section II of this issue of the PROCEEDINGS:

Order and Amplitude of Harmonics in Voltage Wave Forms with Indicating Instruments, by Leslie F. Curtis.

Theory of Probabilities Applied to Failures of Suspension Insulators, by L. M. Klauber.

Predetermination of Synchronous Phase-Modifier Performance, by Hubert V. Carpenter.

Operating Features of a 1000-*Mile*, 220,000-*Volt Trausmission Line*, by R. W. Sorrenson, H. H. Cox and G. E. Armstrong.

The local convention committee, the membership of which was announced in the June PROCEEDINGS, has nearly completed its arrangements for this meeting, and announcements of the program will be mailed by the committee to all Institute members in the Pacific Coast States.

FUTURE A. I. E. E. MEETINGS

New York Meeting.—A joint meeting with the Institute of Radio Engineers will be held in New York on October 1, 1919. The subject of this meeting will be Radio Telegraphy.

Philadelphia Meeting.—On October 10, 1919 a regular meeting of the Institute will be held in conjunction with the American Physical Society. This meeting will be under the auspices of the Electrophysics Committee.

New York Meeting.—A regular Institute meeting under the auspices of the Power Stations Committee will be held in New York on November 14, 1919.

Programs for the above meetings are now being arranged and will be given in full in future issues of the PROCEEDINGS.

FIFTH NATIONAL EXPOSITION OF CHEMICAL INDUSTRIES

Among the interesting features of the Fifth National Exposition of Chemical Industries to be held at the Coliseum and 1st Reg. Armory Chicago, week of Sept. 22, 1919 will be an exhibit of many types of electric furnaces, exhibits of new metal alloys, complete exhibits by the U. S. Bureau of Mines, showing the extraction of metals from their ores, exhibits of numerous new instruments and measuring devices developed largely during the war, health and welfare exhibits. In addition numerous meetings and technical sessions of interest will be held, as listed in the July PROCEEDINGS.

ENGINEERING COUNCIL

REPORTS OF THE NATIONAL SERVICE COMMITTEE

STATUS OF WATER POWER LEGISLATION

The Federal Power Bill which originated in the House was referred to the Senate and turned over to the Committee on Commerce on July 8th. The Senate has been waiting for the House to pass this bill before it began further active work on its water power bills.

It is contemplated that the Esch bill No. 3184 as it passed the House, will be in substance at least, satisfactory to the Senate Committee, and that this legislation will be reported out shortly.

The necessity for legislation embodied in this bill is felt in all parts of the country and especially by engineers who are intimately connected with the projects which it will affect.

The salient features of the Esch bill are the creation of a commission known as the Federal Power Commission, to be composed of the Secretaries of War, Interior, and of Agriculture. To this commission are given the powers heretofore exercised by the Secretaries in connection with water-power development under their several jurisdictions. It was thought better to create a commission consisting of Cabinet officers than a new commission necessitating large appropriations. Moreover, the clerical and expert forces of the several departments are made available for this Federal Power Commission.

The powers of the commission are set forth in detail in the pending bill, as are also the duties and obligations of the grantees upon receiving the licenses provided for in the bill. The terms of the license are also set forth and a continuance thereof for a period not exceeding 50 years. Further provisions relating to recapture or of retaking of the projects upon the termination of 50 years are also fully set forth. Provisions are also made for the regulation of rates to be charged to consumers by the grantees. Penalties are provided for entrance into combinations or monopolies in restraint of trade on the part of grantees. Suitable penalties are prescribed for the violation of the terms of the provisions of the act.

Copies of the bill will be mailed on request to National Service Committee, Engineering Council, McLachlin Building, Washington, D. C.

PAYMENT OF MILEAGE TO ENGINEER OFFICERS

The following extracts from a letter referred to the National Service Committee of Engineering Council explains the unfortunate experience of some of the Engineers who were enrolled in the Reserve Corps at the beginning of the war.:

> Among other things, we were informed that reserve corps officers when ordered to active duty would receive the pay and allowance that officers ordinarily do when changing stations. Any number of western engineers, several of them located in Alaska, applied for commissions in the first engineer reserve corps. After their applications had gone forward the reserve corps was abolished by the War Department. Without receiving any information to this effect these men were telegraphed offers of commissions in the Engineers, U. S. A. They accepted and were ordered to Camp A. A. Humphreys, Va., for duty as students. Upon their arrival they were informed that they would receive no travel allowances at all. The seven cents a mile that they expected was not due them because they had accepted commissions in the regular army, not in the reserve corps. This was the first intimation that they had as to their new status. Most of the men particularly those fron Alaska, had been to a very considerable expense in traveling, as much as $350, in some cases, and naturally consider themselves unfairly treated.
>
> Another instance, which covers my own case, occurred as follows: Some 25 or 30 of us entered the service in the Philippine Islands. We were discharged in the States, most of us in the eastern part. Our discharges came just too late to catch the December transport for the Philippines so we were forced to wait for the January boat which arrives in Manilla about February 15th. We were thus over two months without pay, our army pay having stopped on the date of our

discharge and our pay as civilians not beginning until our arrival in the Philippines. Anticipating these conditions some of the men requested that they be ordered to the Philippines and discharged there or that they be returned to the inactive list in the reserve corps so that they could return to their homes with pay. Both of these requests were refused and the men discharged along with the rest.

A letter of inquiry in regard to this complaint was addressed to the Secretary of War by Engineering Council and elicited a reply from the Chief of Engineers, U. S. A. stating that the criticisms voiced in the above letter were justified, and recommending that a draft of suitable legislation be submitted to Congress to correct the inequities described.

Grateful acknowledgment has been made to the reply of the Chief of Engineers.

A bill has been introduced in the House by Mr. Johnson, of Washington, authorizing and directing the Secretary of War to pay mileage from the place of residence to first station to all officers who accepted commissions after signing blanks containing a provision that the Government would allow travel expenses at the rate of seven cents per mile to applicants who might be commissioned. In order that this or similar legislation may be enacted into law, interested parties should send in detailed explanation of their cases.

Former Engineer officers who have had similar experiences to those described above should communicate with the National Service Committee, Washington, D. C. The committee can do nothing without the cooperation of the engineers most interested in the matter.

PAST SECTION MEETINGS

Baltimore.—June 5th, 1919, Engineers Club. Illustrated address by Dr. J. B. Whitehead on "Submarine Detection." Attendence 90.

Detroit-Ann Arbor.—June 20, 1919, Detroit Board of Commerce. Addresses on Institute Development by Professors J. C. Parker and H. H. Higbie, and Messrs, E. M. Walker and F. J. Molitor. Attendance 50.

Minnesota.—May 20, 1919, University of Minnesota. Papers: (1) "Construction Features of Some Recent Electrical Generating and Distributing Plants" by Wm. T. Walker; (2) "Steam Power Plant Operation at the Riverside Plant of the Minneapolis General Electric Company" by H. S. Whiton; (3) "A Synopsis of the Work of the Bureau of Conservation" by Hans J. Meyer. Attendance 85.

June 17, 1919, University of Minnesota. Addresses as follows—(1) Engineering as Relates to the Army" by Major William Pierce Cowles; (2) "Aviation Field Engineering" by Lieut. Vernon S. Beck. Election of officers—chairman, Fred G. Dustin; secretary, Leo H. Cooper. Attendance 23.

Panama.—June 8, 1919, Cristobal, C. Z. Inspection trip to the new Panama Railroad Pier No. 6. Joint meeting with the Engineers Club. Attendance 26.

Portland.—June 10, 1919, University Club. Paper: "Ranging by the Flash and Sound Method" by E. F. Whitney.

Spokane.—June 13, 1919, Chamber of Commerce. Discussion of "The Metric System." Joint meeting with other engineering societies. Attendance 31.

Philadelphia.—June 9, 1919, Howard McCall Field. Election of officers as follows—Chairman, C. E. Clewell; secretary-treasurer, Ross B. Mateer; assistant secretary, Raymond Bailey; managers, P. H. Chase, L. J. Corta, E. B. Tuttle; hold over managers, C. E. Clewell, N. E. Funk, Baxter Reynolds. The meeting took the form of an outing at the athletic field of the Philadelphia Electric Company, with sports in the afternoon, a dinner in the pavilion and dancing in the evening. Attendance 90.

ENGINEERING SERVICE BULLETIN

Opportunities.—The Institute, is particularly anxious to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in this BULLETIN. The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Services Available.—Under this heading brief announcements (not more than fifty words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office files.

Note.—Copy for publication in the BULLETIN should reach the Secretary's office not later than the 20th of the month if publication in the following issue is desired. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

Engineering Societies Employment Bureau.—This is a joint bureau under the auspices of the Engineering Council. The Institute's employment service is coordinated with that of the joint bureau.

OPPORTUNITIES FOR SERVICE

V-542. Engineer, experienced in the design of transformers. Permanent position for man who can qualify. State age, training, experience and salary expected.

V-543. Engineer, familiar with the design and application of fractional horse power motors, both a-c. and d-c. Opportunity to develop with a rapidly growing business. In replying give experience.

V-544. Engineer, experienced in the design of induction motors. Permanent position for man able to do independent work. Please state training and experience.

V-545. Experienced designing engineers, competent to do original design work on direct current and generators of small and medium sizes. In replying state education, experience and salary expected.

V-546. Assistant Professor of Electrical Engineering. A large university in the middle west desires to appoint two assistant professors in electrical engineering, one of whom has had specialized experience in central station and electric railway work. Engineers who have had from five to ten years' experience in the engineering rather than in the teaching field desired. Duties will be teaching and lecturing. Salary $2000. to $2250. per school year of 9 months.

V-547. Instructors in electrical engineering for laboratory work are wanted by a large middle western university. Men with a few years of general experience in the engineering field desired. Two appointments are available. Salary $1400. to $1700. per school year of 9 months.

V-548. Instructors in electrical engineering, principally for laboratory instruction. Experience in testing or operation desirable. Opportunity for advanced study. Two positions open at $1250. and $1500. Address: Electrical Engineering Department, Sheffield Scientific School, New Haven, Conn.

V-549. Professor of electrical engineering wanted for technical school in Shanghai, China. Class room and laboratory work. Some knowledge of steam-turbine testing required. Salary Mex. $4000. to Mex $4700. according to qualifications; equivalent to U. S. $3600. to U. S. $4200. at present rate of exchange. Residence furnished married man. Three-year contract. Transportation paid. Further information from Employment Bureau of A. I. E. E.

V-550. Instructorship open in electrical engineering. Location Ohio. Salary $1800. Vacation allowance about six weeks. Applicants must have had thorough technical training, at least one year practical experience, and must possess tact and judgment. Give experience in detail, age and references.

V-551. Mechanical draftsman, with several years' experience in designing complete d-c. electric motors, ½ h. p. to 150 h. p., from engineer's specifications. Excellent opportunity for the right man. Location near New York City. State age, experience in detail and salary expected.

V-552. Vacancy in Electrical Engineering Department of university on northern Pacific Coast. Salary $2000. for nine months service. Applicant must be able to teach fundamentals of direct and alternating current, and give courses in electrical machine design and power transmission. In reply give experience in detail, age, etc.

V-553. A technical school in the Middle States needs an assistant instructor in the electrical department. Must have had practical experience in the field in either electric light and power work, or telephony, preferably both. Previous teaching experience desirable but not necessary. Must be able to conduct class room work in electricity, also laboratory and practical work in installation and maintenance methods. State age, experience, education, references and salary expected in first letter. School year, nine months.

V-554. Wanted, by large eastern university, an instructor in electrical engineering. Both class room and laboratory work. Salary $1500. to $2000., depending upon experience of applicant. In reply state both educational and practical experience.

V-555. The University of Pennsylvania, Electrical Engineering Department, has an opening for an instructor in electrical engineering at a salary of from $1200. to $1500., according to the experience of the applicant. Address: Dr. Harold Pender, R. F. D. 2, Surry, Maine.

SERVICES AVAILABLE

1355. A newly graduated electrical engineer desires position with large manufacturing concern. Brazilian, 23 years old, single, excellent health. Willing to travel or reside anywhere. Available at once.

1356. Electrical engineer, 25 years old and married, Associate A. I. E. E., desires change. At present in charge of wire and cable testing laboratory. Would like similar work, or plant electrical engineer. Will gladly furnish references and history of past experience, which has been varied. Location optional. Salary to start $2500.

1357. Electrical engineer wants general engineering position. Capable of design of L. T. and H. T. installations, bus structures, switchboards in power and substations. Experienced in general illumination, lamps; machine and instrument testing; relay protection of transmission lines; electric railway power, cars and control equipment. Graduate of Lowell Institute. Thirteen years' experience; age 33. Salary desired $2500.—$3000. yearly.

1358. Aggressive, ambitious young man with excellent credentials, University graduate, electrical-mechanical. Speaks English, French and Spanish correctly. Experienced along engineering, shop, sugar machinery, draughting, import, export, sales and publicity. Desirous of connecting with exporting or consulting firm in New York City or vicinity. Employed by large and progressive electrical exporter.

1359. Young man, age 34, wants position of superintendent or assistant of power company. Twelve years of broad experience in operation, maintenance and load dispatching with steam and hydroelectric systems with voltages up to 110,000. Expert in remedying operation and insulator troubles. Testing, distribution and construction experience. Salary $175. a month.

1360. Electrical engineer; graduate E. E., Associate A. I. E. E., age 26, single; two years G. E. test, at present in engineering office. Have had accounting and business training. Desires position as electrical engineer or as assistant manager in power plant; prefer the West. Best references. Monthly salary at start $150. Available on application.

1361. Technical graduate, five years experience with Westinghouse Electric on apprenticeship course and in factory and field construction work, seven and one-half years in charge of construction work for public utility light and power company, at present connected with branch of U. S. Government on war work nearing completion, desires to make connection with public utility, manufacturing or industrial plant, location no object, age 33, married. Salary $3000.

1362. Teaching position wanted. Graduate as Bachelor of Science of technical school in central west and as Master of Science of eastern college, desires position as instructor or assistant professor, the latter preferred, in electrical engineering. Two years General Electric test experience.

1363. Electrical engineer, sixteen years' experience in operation, maintenance and repairs, also construction of electrical equipments, desires position; at present disengaged. No restriction as to location. Technical training. Age 38, married. Minimum salary $2100. per year. Just released from service in Construction Division, U. S. Army.

1364. Electrical Distribution Engineer, thoroughly competent to design, install or maintain an overhead or underground electrical distribution system. Technical college graduate E. E. Executive ability. Five years practical experience. Excellent references. Age 31, married. Desires permanent employment where advancement depends upon experience, knowledge and results. Temporarily employed. Salary $2500.

1365. Electrical engineer desires position as assistant, resident or designing engineer. College graduate. Eight years electrical manufacturing, eight years constructing and operating. Handled men last ten years. Specially qualified as designing or assistant engineer, power stations, transmission and distribution, industrial control, electrical rolling mills. Have handled estimates, specifications, and correspondence seven years. Lowest salary $3600. English, married.

1366. Electrical and mechanical engineer, M. I. T. graduate. Recently Lieutenant in Naval Reserve Force. Available for position requiring engineering and business ability. Married, age 35. Eight years' experience as consulting mechanical and electrical engineer, two years general manager traction company, two years production engineer for large company. Highest references. Location foreign or domestic. Salary $5000.

1367. Electrical engineer, expert on motor drives, thirteen years responsible executive experience in industrial and power plant work, generators, switchboards, telephone wiring, line work. University graduate, American, Christian, 39, married. Desires position with large industrial plant or central station as engineer or power salesman.

1368. Graduate electrical engineer, two years central station construction and design, one year G. E. test, and two years teaching, wishes position with consulting engineer or progressive engineering concern offering good chances for advancement. Age 28 years, single, Associate A. I. E. E., member N. E. L. A. Willing to sacrifice to get place desired. Best references.

1369. Graduate electrical and mechanical engineer. Four years General Electric and Allis-Chalmers tests. Five years in general engineering and commercial departments of the G. E. Co. One year as assistant to the chief engineer and superintendent of operating and construction departments of large hydro-steam transmission company. Age 35.

1370. Graduate electrical engineer, age 28, unmarried, desires position as fire prevention engineer, where opportunities exist for individual growth. Have had several years' experience in the supervision of the development, design and manufacture of devices, and the maintenance and operation of systems employed in protective telegraphy. Salary desired to start $2500.

1371. Electrical engineer, college graduate 1911, expert on power transmission line, substation and distribution system, design, estimate, construction, operation, maintenance, other valuable engineering and business experience, desires position as superintendent or engineer of transmission or distribution. Employed. Minimum salary $2400.

1372. Engineering graduate (1917) with B. S. E. E. and M. S. degrees from southern state university desires position as instructor in physics and electrical engineering, preferably in South or West. Fellow in these subjects during graduate year. Ex-Army Officer. One year in public utility training school. Salary expected $1500.

1373. Electrical engineer, Lehigh graduate 1911. Four years assistant electrical engineer anthracite mining company; three years electrical engineer railroad valuation. Associate A. I. E. E. and Illuminating Engineering Society; Army officer about to be discharged; can obtain discharge on short notice.

1374. Mechanical engineer B. S. and M. E., six years on power station construction, seven years investigation of municipal departments and preparation of special reports on fire protection. Experienced in steam engine, gas engine and boiler testing. Desires position as fire protection engineer. Employed at present.

1375. Electrical engineering graduate (1917) with post graduate degree from Massachusetts Institute of Technology and Harvard desires responsible position preferably with electric railroad or consulting engineering firm. Experienced in electrical testing and electric railway research. Age 25 and single. Available on short notice.

1376. Engineer-Salesman in complete charge for several years, thoroughly familiar with magnet wire trade in

U. S., Canada and export, is ready to change connection. Now with one of the largest manufacturers. Well known, with large following. Can arrange interview.

1377. Executive, engineer, manager, $2500. High grade man with broad experience and technical training, re-entering civil life after service abroad in the U. S. Navy. At present on Pacific Coast but available for suitable connections domestic or foreign. Experienced in developing and manufacturing complicated control and signaling apparatus. Expert on industrial control. Highest references.

1378. Electrical engineer who for fourteen years has been associated with one of the largest electrical manufacturers in various capacities in designing and sales engineering, desires position with comparatively small but reliable manufacturer or a "live" central station. Age 33, married. Minimum salary $3000. Will gladly furnish dependable references.

1379. Electrical engineer, graduate E. E., married; fifteen years' experience; power station, substation and industrial station design; construction; transmission; distribution; railway and light and power work; executive and business experience. Age 32. Salary $3000. minimum.

1380. Electrical engineer, technical graduate. Wide experience in construction and maintenance of power plant machinery for traction lines, and heavy traction equipment. Now in charge of rolling stock and shops for large interurban system. Good organizer. Salary $3600. to $4000. according to location and other conditions.

1381. Electrical and mechanical engineering graduate. Age 26. Associate A. I. E. E. Two years' experience testing and inspecting electrical devices. One year on experimental development work. References regarding ability available. Desires permanent position with opportunity for advancement. New York or vicinity preferred. Available immediately. Salary expected $2000.

1382. Technical graduate, age 25, married, three years electrical and mechanical experience, desires position. One year with light and power corporation as junior testing engineer. At present Lieutenant (junior grade), U. S. Navy, engineering duty, but expect early discharge.

1383. Electrical and aeronautical engineer. Age 28. At present Captain, U. S. A. Chief Engineer of an aviation repair depot, desires position with an electrical or manufacturing company; broad experience in electrical testing and design of electrical and aeronautical equipment. Executive and administrative ability. Expect discharge by September 30. Salary $4000.

1384. An associate professor of electrical engineering in a large state university; fifteen years' experience in teaching electrical engineering subjects and the author of several well known texts; desires to change location. Salary $3000.

ENGINEERING SOCIETIES LIBRARY

The library, which comprises the individual libraries of the American Institute of Electrical Engineers, the American Society of Mechanical Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Civil Engineers, and the United Engineering Society, is located on the thirteenth and fourteenth floors of the Engineering Societies Building. In addition to engineering works it contains general reference books on allied sciences such as Physics, Mathematics and Chemistry. The library also contains publications of practically all the engineering societies in the world as well as current and bound sets of more than 1,000 engineering periodicals in English and other languages.

In order to place the facilities of this great engineering library at the disposal of persons residing out of town, a Library Service Bureau has been established, and a staff of expert searchers and translators is prepared to cover almost any engineering topic. Charges for service are at actual cost. Photostat copies of prints, drawings, etc., are $0.25 per 10 x 14 inch sheet.

All communications should be made as definite as possible so that the information received may be what is desired and not include collateral matter of no interest. The time spent in searching for such collateral matter will be saved, and information sent more promptly and in more usable shape.

Members who may desire it will be kept informed regarding current publications on any engineering subject for a small annual fee.

The library is conducted as a free public library of reference. It is open to the public from 9 a m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a.m. to 6 p.m.

Book Notices.—(June 1–June 30, 1919) Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

THE BLIND.

Their Condition and the Work Being Done for Them in the United States. By Harry Best. N. Y., The Macmillan Co., 1919. 17 + 763 pp., illus., tab., 8 x 6 in., cloth, $4.

The particular sections of this comprehensive survey likely to interest engineers are those treating of the industrial employment of the blind and of indemnities for the loss of sight. Both topics are given full consideration. Attention is given to the theoretical aspects of industrial establishments for the blind, the organization and results of present establishments, and the possible and present employment of the blind in general occupations. The payment of indemnities through suits at law, insurance policies and workingmen's compensation acts are also described very fully.

BOILER CHEMISTRY AND FEED WATER SUPPLIES.

By J. H. Paul. Lond. & N. Y., Longmans, Green and Co., 1919. 242 pp., 1 pl., tab., diag., 9x6 in., cloth, $4.50.

The lack of any adequate discussion of the chemical reactions which occur in high pressure boilers fed with natural waters, and of the effects of these reactions upon the steaming capacity of the boiler and upon the metal of which it is made, have led the author to prepare this volume, in which he gives the knowledge gained by long practical experience with boilers under varied circumstances and conditions. As far as possible, he has stated the facts and his conclusions in the language of everyday life.

THE CANADIAN MINING MANUAL. 1918.

A handbook of information concerning the Minerals and Mines of Canada. Edited by Reginald E. Hore. Toronto, Mines Publishing Co. (copyright 1919) 352 pp., illus., pl., por., maps, tab., diag. 11 x 9 in., cloth, $5.

This is the fourth edition of this handbook of Canadian minerals, metals, mining and metallurgical companies, in which the chief objects are to present concisely, matter of interest to persons connected with the mining industry and to attract attention to the possibilities of Canadian mineral resources. A preliminary survey of progress in 1918 and a summary of the official reports for 1917 are given for each province and product. There are also a number of special articles on topics of interest, a directory of mining companies and a list of the producers of various mine products.

THE ELEMENTS OF ASTRONOMY FOR SURVEYORS.

By R. W. Chapman. Lond., Charles Griffin and Company, Ltd.; Phila., J. B. Lippincott Co., 1919. 247 pp., tab., 56 diag., 8 x 6 in., cloth, $1.75. (Gift of J. B. Lippincott).

The author of this small volume has attempted to provide students of surveying with an elementary exposition not only of the practical methods of observation and computation, but also of the main principles by which the formulas are derived. The methods of observation are illustrated by fully worked out actual observations and prominent attention is given to the effects of observational and instrumental errors.

ENGINEERING DESCRIPTIVE GEOMETRY AND DRAWING.

A Treatise on Line Drawing, Descriptive Geometry, and Engineering or Mechanical Drawing, for the Use of Midshipmen at the United States Naval Academy. By Frank W. Bartlett and Theodore W. Johnson. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1919. 617 pp., illus., pl., tab., 9 x 6 in., cloth, $5.50.

This volume consists of three independent treatises on Line Drawing, Engineering Descriptive Geometry, and Engineering Drawing. Collectively they represent the course in drawing at the United States Naval Academy and are intended to provide a complete course for students with no previous knowledge of mechanical drawing.

Part one has been written to replace Bartlett's Mechanical Drawing. Part two, which treats of the science of orthographic projection, was issued as a separate work in 1910 and has been revised to date. Part three, the work of Prof. Johnson, deals with the application of Parts one and two to the needs of engineers, draftsmen and mechanics, for practical. construction of machines of every kind. Part three is also issued separately for the use of those who wish a general course in mechanical drawing.

EXCAVATION.

Machinery, Methods and Costs, Including a Revision of "Excavating Machinery." By Allen Boyer McDaniel. 1st edition. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1919. 18 + 542 pp., 209 illus., 9 x 6 in., cloth, $5.

Frequent requests for information on recent types of excavators and the newer uses of older types, have led the author of this work to prepare it to replace his "Excavating Machinery," published in 1913. The present work is divided into two sections; the first describes the construction, method and typical cost of operation of each type of excavator, the second is a comparative study of the efficient and economic use of the different types of machines in the various fields of construction work. Highway and railroad construction, reclamation, river, harbor, canal and municipal work, quarrying, tunneling and mining are considered. References to the literature are included.

IRRIGATION ENGINEERING.

By Arthur Powell Davis and Herbert M. Wilson. 7th edition, revised and enlarged. N. Y., John Wiley and Son Inc.; Lond., Chapman & Hall, Ltd., 1919. 640 pp., 249 illus., 59 tab., 9 x 6 in., cloth, $4.50.

The early editions of Wilson's Manual of Irrigation Engineering were especially valuable because of the authors familiarity with large irrigation works in India and Egypt. Subsequent activity in irrigation, particularly in the United States, and developments in related lines of municipal water supply and hydroelectric construction, have presented new problems and evolved new solutions of old ones. Social and economic differences between America and Asia have also caused distinctive changes in practice. In preparing this revised edition, Mr. Davis has taken the changed situation into consideration, with the result that the book is in the main rewritten and rearranged, and contains much new material.

LIQUID FUELS FOR INTERNAL COMBUSTION ENGINES.

A Practical Treatise for Engineers and Chemists. By Harold Moore. N. Y., D. Van Nostrand Co., 1918. 15 + 200 pp., 49 illus., tab., 9 x 6 in., cloth, $5.

The author describes in part one of this volume the chemical differences between the various fuels; petroleum, shale oil, coal and lignite tars, wood and peat distillation products, oils and alcohols, which are used for internal combustion engines. In part two of the book these fuels are classified according to their suitability for use in engines fitted with carburetters, vaporizers or atomizers. Part three presents methods for the examination and valuation of liquid fuels with a view to their use in these engines, the procedure in such cases being different from that used in determining their value for external combustion.

MAGNETISM AND APPLICATIONS OF MAGNETS.

By John D. Ball. (School of Practical Electricity, Book 4) Milwaukee, Electroforce Publishing Co., (copyright 1919) 113 pp., 95 illus., tab., 10 x 7 in., cloth, $1.50. (Gift of author).

This volume, which is one of a series of textbooks for technical high schools, trade schools, etc., combines a brief description of the laws and principles of magnetism and the commercial uses of magnets with a selection of laboratory experiments to illustrate the theories of magnetism and electro-magnetism. Only elementary mathematics is used.

MILITARY GEOLOGY AND TOPOGRAPHY.

A Presentation of Certain Phases of Geology, Geography and Topography for Military Purposes. Herbert E. Gregory, Editor. Prepared and issued under the auspices of the Division of Geology and Geography National Research Council. New Haven, Yale University Press. 1918. 281 pp., illus., pl., maps, 9 x 6 in., cloth, $1.25.

This book is the result of a preliminary effort to meet the need which the Great War has demonstrated for a more widely diffused knowledge of geology as an aid in conducting military operations and in the solution of economic problems relating to raw materials. Attention is given mainly to those facts and principles that have proven to be applicable to military problems. Bibliographies for supplementary reference study are included.

MOTOR VEHICLE ENGINEERING.

Engines (for Automobiles, Trucks and Tractors). By Ethelbert Favary. 1st edition. N. Y., McGraw-Hill Book Company, Inc.; Lond., Hill Publishing Co., Ltd., 1919. 12 + 333 pp., 133 illus., 39 tab., 9 x 6 in., cloth, $3.

The present volume, the first of a contemplated series intended to give designers, engineers and students a concise summary of modern practice in automobile design and construction, deals with engines. It illustrates standard designs for all engine parts and gives the formulas for determining the strength and dimensions of these parts, together with other useful information. Only simple mathematics is used.

PUMPING MACHINERY.

A Treatise on the History, Design, Construction and Operation of Various Forms of Pumps. By Arthur M Greene, Jr. 2nd edition, revised. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1919. 703 pp., 504 illus., tab., 9 x 6 in., cloth, $4.

Gives a brief, historical review of the development of pumping machinery, describes the action of a number of common forms of pumps and states the methods of design of pumping apparatus. It is intended to develop certain general principles of mechanics which are applicable to pumping machinery as well as to train the student in application of the theoretical portions of an engineering course. The descriptive chapters on modern pumps have been prepared from the catalogues and bulletins of manufacturers and from current technical literature. A full bibliography is included.

SHORE PROCESSES AND SHORELINE DEVELOPMENT.

By Douglas Wilson Johnson. 1st edition. N. Y., John Wiley and Sons. Inc.; Lond., Chapman & Hall, Ltd. 1919. 17 + 584 pp., 149 illus., 73 pl., 9 x 6 in., cloth, $5.

Professor Johnson has recorded in compact form the results of an extended study of the scattered literature on shore processes and shoreline forms. Water waves, the work of waves, current action, the development of the shore profile and the shoreline, shore ridges and minor shore forms are discussed, and a statement of the fundamental principles which seem best established is given. The author hopes that the book will prove useful to engineers, geologists and geographers. Full lists of references and a bibliography are included.

WATERPROOFING ENGINEERING.

For Engineers, Architects, Builders, Roofers and Waterproofers. By Joseph Ross. 1st edition. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1919. 10 + 442 pp., 140 illus., 41 tab., 9 x 6 in., cloth, $5.

The absence of any systematic treatise on waterproofing has led to the preparation of this book, which is based on the author's practical experience and researches, as well as his study of the existing literature. The function of waterproofing, the systems in use, methods and results are described, and specification and cost tables are given. A useful glossary of waterproofing terms and a bibliography are appended.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before August 31, 1919.

Bean, H. M., Newark, N. J.
Black, R., Jr., Philadelphia, Pa.
Campbell, T. V., Port Newark, N. J.
Cegavske, H. E., E. Pittsburgh, Pa.
Cholet, L., New York, N. Y.
Conway, U. W., Washington, D. C.
Cooper, G. S., (Member), New Brighton, N. Y.
Coutant, T. S., Clintondale, N. Y.
Davis, H. A., Rochester, N. Y.
Doubt, R. A., Chicago, Ill.
Driver, H. E., Chicago, Ill.
Felix, E. H., Sunnyside, L. I., N. Y.
Fell, D. A., Mayville, Wis.
Fogler, W. A., Philadelphia, Pa.
Friedman, L., New York, N. Y.
Geiser, J. D., Pittsburgh, Pa.
Ghegan, J. J., (Member), New York, N. Y.
Giese, R. C., New York, N. Y.
Hartvig, C. L., Rock Island, Ill.
Heffner, O. C., Washington, D. C.
Hixon, G. C., Port Angeles, Wash.
Huguemont, L. A., Newark, N. J.
Jehlen, C. F., New York, N. Y.
Johnson, A. B., Norway, Mich.
Kahler, G. W., San Francisco, Cal.
Kaiser, C., (Member), New York, N.Y.
Keath, H. B., St. Louis, Mo.
Kerns, B. L., Seattle, Wash.
Kubota, K., New York, N. Y.
Libby, E. S., W. Lynn, Mass.
Mead, C. E., Gadsden, Ala.
Mixer, A. L., (Member), Camp Merritt, N. J.
Meharg, L., Washington, Pa.
Molina, J., Yucatan, Mex.
Mooney, P. F., Jackson, Mich.
McGhie, W. G., St. Catharines, Ont.
Olds, T. H., Denver, Colo.
O'Sullivan, F. A., Boston, Mass.
Page, E. R., Pittsfield, Mass.
Pastor, F. W., Elizabeth, N. J.
Patterson, H. H., Ft. Wayne, Ind.
Pattison, D. R., Indiana, Pa.
Plank, H. H., Toledo, Ohio
Porham, A. H., Atlanta, Ga.
Ransom, A. E., New York, N. Y.
Rasmussen, R. A., Chicago, Ill.
Reardon, H. B., Jr., (Member), Norfolk, Va.
Richmond, H. B., Cambridge, Mass.
Sandberg, J., New York, N. Y
Shannon, J. W., Port Huron, Mich.
Sillcox, L. K., (Member), Milwaukee, Wis.
Simmonds, E. P., New York, N. Y.
Spring, R. H., Wilmington, Del.
Stoller, H. M., (Member), New York, N. Y.
Sweet, G. L., New York, N. Y.
Taylor, H. T., Hazard, Ky.
Thayer, C., Oxford, N. C.
Thelen, J., Chicago, Ill.
Thomas, R. L., Baltimore, Md.
Thormalen, A., Oshawa, Ont.
Timmons, J. S., Yonkers, N. Y.
Tully, W. J., Philadelphia, Pa.
Wacker, H., Baltimore, Md.
Wood, J. D., E. Pittsburgh, Pa.
Yokota, T., Newark, N. J.

Total 65.

Foreign Applications

Bean, L. P. R., N. So. Wales. Aus.
Beasley, I. E., Darien, C. Z.
Blakemore, E., Horwich, Lancashire, Eng.
Fairey, A. R., (Member), Manchester, Eng.
Henderson, H. W. W., Aden, Arabia
Imbery, A., (Member), Leeds, Eng.
Jackson, R. A. F., Motherwell, Scotland
Lagrange, D., Bruxelles, Belgium
Lohr, H., Arnhem, Holland
Molloy, V. L., Sydney, Aus.
Scott-Taggart, J., Bolton, Eng.
Smith, R. T., (Member), London, Eng.
Sugimura, N., Shiba, Tokyo, Japan

Total 13.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its regular monthly meeting, held on July 14, 1919, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

Barnholdt, Harold L., Designing Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Morecroft, John H., Associate Professor in Electrical Engineering, Columbia University, New York, N. Y.

To Grade of Member

Arana, Victor M., Consulting Electrical Engineer, Head of Electrical Dept., National School of Arts and Crafts, Lima, Peru, S. A.

Johnson, Carl E., Vice-President & General Manager, U. S. Electrical Mfg. Co., Los Angeles, Cal.

Moore, Nelson S., Electrical Engineer, Lewis and Roth Corp., Philadelphia, Pa.

Stanley, Howard A., Superintendent, Fall River Electric Light Co., Fall River, Mass.

Stoltz, G. E., General Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Young, W. E., Assistant Manager, Apparatus Dept., Canadian General Electric Co., Toronto, Ont.

PERSONAL

Major J. R. Worth, Construction Division, U. S. A. is stationed at Pittsburgh, Pa., c/o West Penn Power Co., Beedeedum Trees Bldg., as Government Constructing Quartermaster for three steam-electric plants. He will probably remain about a year.

Dr. V. Bush has been appointed Associate Professor of Electrical Engineering at the Massachusetts Institute of Technology. Dr. Bush is a graduate of the Electrical Engineering Course of Tufts College receiving an M. S. degree in 1914. He received the degree of Doctor of Engineering from M. I. T. in 1916. After graduating from Tufts he became an instructor in the Tufts staff and was later made an Assistant Professor. During the course of scientific researches in the war, Dr. Bush was associated with the New London researches of the United States Navy for the detection of submarines. Dr. Bush is now engineer of the American Radio and Research Co.

G. L. Crosby, Sales Manager of the Roller-Smith Company announces the establishment by his company of agency arrangements with L. B. Gottschall, 211 N. St. Paul Street, Dallas, Texas. The complete line. of the Roller-Smith Company products will be handled by Mr. Gottschall who has had extensive experience in the sale and installation of electrical apparatus in his locality.

OBITUARY

G. R. Baker died at Jabl-us-Siraj, Afghanistan, on November 11, 1918 from the effects of typhoid-pneumonia. He was buried in British territory in Peshawer, India. Mr. Baker had been acting as first Assistant to the Chief Engineer of the Kabul Hydroelectric Scheme and just before his final illness had taken charge of the plant and was to remain as Chief Engineer in charge. He had been formerly in the employ of the General Electric Company as Construction Engineer and had worked on the Panama Canal installation, erected plants in Cuba and the Western States. He became an Associate in the Institute in 1915.

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(Term expires July 31, 1921)
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T. COMMERFORD MARTIN, 1887-8
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK JULIAN SPRAGUE, 1892-3.
EDWIN J. HOUSTON, 1893-4-5.
*LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-02.
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN W. LIEB, 1904-5
SCHUYLER SKAATS WHEELER, 1905-6
SAMUEL SHELDON, 1906-7.
*HENRY G. STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09.
LEWIS B. STILLWELL, 1909-10
DUGALD C. JACKSON, 1910-11.
GANO DUNN, 1911-12.
RALPH D. MERSHON, 1912-13.
C. O. MAILLOUX, 1913-14.
PAUL M. LINCOLN, 1914-15.
JOHN J. CARTY, 1915-16.
H. W. BUCK, 1916-17.
E. W. RICE, Jr., 1917-18.
COMFORT A. ADAMS, 1918-19.

***Deceased.**

LIST OF SECTIONS

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Indianapolis-Lafayette, G. E. Varney, D. C. Pyke
Ithaca, Alexander M. Gray, John G. Pertsch, Jr.
Kansas City, Mo., W. F. Barnes, W. F. Barnes
Los Angeles, J. H. Cunningham, Clem A. Copeland
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Madison, C. M. Jansky, L. E. A. Kelso
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*Iowa, Univ. of
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Washington, Univ. of, J. R. Tolmie, Glen H. Walker
West Virginia Univ.
*Worcester Poly. Inst.
Yale University, P. C. O'Brien, Donald F. Hine

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*Inactive at present, due to the war.

PROCEEDINGS

OF THE

American Institute of Electrical Engineers

Vol. XXXVIII
Number 9

SEPTEMBER, 1919

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TABLE OF CONTENTS

Section I.—Institute Affairs

Pacific-Coast Convention 811
Joint A. I. E. E. and I. R. E. Meeting in New York 811
Joint Meeting in Philadelphia, October 10-11, 1919 811
Philadelphia Meeting of American Chemical Society 812
National Safety Council to Meet in Cleveland 813
A. I. E. E. Directors Meeting August 12, 1919 813
Andrew Carnegie 814
The Engineer Corps Under the Proposed Army Reorganization 814
New Appointments at Massachusetts Institute of Technology 815
Engineering Council:
  Appointment of Engineer on Interstate Commerce Commission 816
  Strengthening of Patent Office 816
The Report of Delegates to France to Founder Societies 817
Applications for Election 817
Associates Elected August 12 818
Members Elected August 12 822
Fellow Elected August 12 822
Transferred to Grade of Member August 12 823
Transferred to Grade of Fellow August 12 823
Recommended for Transfer 824
Students Enrolled 824
Personal 824
Engineering Service Bulletin 825
Engineering Societies Library 828
Development of the Institute 831

Section II.—Papers and Reports

California 220,000-Volt—1100-Mile—1,500,000-Kw. Transmission Bus. By R. W. Sorenson, H. H. Cox and G..E. Armstrong , Los Angeles, Cal., September 18-20, 1919 1027
Some New Formulas for Reactance Coils. By H. B. Dwight 1039
Inherent Limitations on Transformations Possible by Stationary Apparatus. By Joseph Slepian 1061

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American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXVIII **SEPTEMBER, 1919** **Number 9**

THE PACIFIC COAST CONVENTION

The eighth annual Pacific Coast Convention will be held in Los Angeles, California, September 18-20, 1919, under the auspices of the Los Angeles Section. The program as arranged by the local committees insures important technical sessions as well as many pleasant social features.

The technical program is as follows:

1. *California 220-Kv., 1100-Mile, 1,500,000-Kw. Transmission Bus*, by R. W. Sorensen, Professor of Electrical Engineering, Throop College of Technology, and H. H. Cox and G. E. Armstrong, of the Southern California Edison Company.
2. *Predetermination of Synchronous Phase Modifier Performance*, by Hubert V. Carpenter, Dean of Mechanic Arts and Engineering, State College of Washington, Pullman, Wash.
3. *Theory of Probabilities Applied to Failures of Suspension Insulators*, by L. M. Klauber, of San Diego Consolidated Gas and Electric Company.
4. *Order and Amplitude of Harmonics in Voltage Wave Forms with Indicating Instruments*, by Leslie F. Curtis, Assistant Professor of Electrical Engineering, University of Washington.
5. *Symposium on Operating Difficulties.* This symposium will consist of a number of valuable short papers from many sources, covering various operating troubles.

Paper No. 1 appears in this issue of the PROCEEDINGS and papers Nos. 2, 3 and 4, in the August PROCEEDINGS. The Symposium papers will be read from manuscript.

The Entertainment Committee promises a splendidly arranged program, to be announced at the convention, of special interest to ladies, who are cordially invited to attend.

JOINT A. I. E. E. AND I. R. E. MEETING IN NEW YORK

A joint meeting of the American Institute of Electrical Engineers and the Institute of Radio Engineers will be held in the Auditorium of the Engineering Societies Building, 33 West 39th Street, New York, on October 1, 1919, at 8:15 p. m.

Three papers will be presented as follows:

1. *Trans-Oceanic Radio Telegraphy*, by E. F. W. Alexanderson, of the General Electric Co.
2. *Telephone Repeaters*, by F. B. Jewett and B. Gherardi, both of the Western Electric Co.
3. *Principles of Radio Transmission and Reception with Antenna and Coil Aerials*, by J. H. Dellinger, of the Bureau of Standards.

JOINT MEETING IN PHILADELPHIA

October 10-11, 1919

A joint meeting of the American Institute of Electrical Engineers and the American Physical Society will be held in Philadelphia, at the Bellevue-Stratford Hotel, on Friday and Saturday, October 10-11, 1919.

The technical sessions on Friday will be held in the Clover Room of the Bellevue-Stratford and the subscription dinner Friday evening in the Stratford Room. The technical sessions on Saturday will be held at the works of the Leeds and Northrup Company, where a complimentary luncheon will be served by the company.

The program is as follows:

FRIDAY, 9:00 A. M.

Session of the Physical Society

Atomic Structure. Paper by P. W. Bridgeman and Irving Langmuir. Discussion by Saul Dushman and others. It is intended to make this interesting to engineers as well as physicists.

FRIDAY, 2:30 P. M.

Session of the A. I. E. E.

1. *The Arrangement of Atoms in Metals*, by Dr. A. W. Hull of the General Electric Research Laboratory. An X-ray study of crystal structures, a demonstration with models of crystals will be shown. (Written for engineers).
2. *The Oscillating Vacuum Tube as a Generator of Electrical Power*, by Professors J. H. Morecroft and H. T. Friis, both of Columbia University. Lantern slides of oscillograph records.
3. *Electromagnetic Induction*, by Dr. J. S. Barnett of the Carnegie Institute, Washington.
4. *Piezo Electrical Effect*, by Dr. A. M. Nichols of the Western Electric Company. (Demonstration).

FRIDAY, 6-00 P.M.

Subscription Dinner

Five minute talks by presidents of the two societies.

FRIDAY, 8:00 P.M.

Technical papers by Prof. H. A. Bumstead of Yale University, and Mr. J. J. Carty, Vice-president of the American Telephone and Telegraph Company.

SATURDAY MORNING

Session of the Physical Society

Inspection of the Leeds and Northrup Plant.

Two semi-technical papers by the Research Laboratories of Leeds and Northrup Company.

SATURDAY NOON

Complimentary Luncheon by the Leeds and Northrup Company.

Automobile ride around Germantown.

SATURDAY AFTERNOON

Regular Physical Society papers.

There will probably be opportunity for technical excursions to the Welsbach factory or a steamer ride on the Delaware River to Chester at 10:30 Friday morning. The steamer ride will be available Saturday morning also.

PHILADELPHIA MEETING OF AMERICAN CHEMICAL SOCIETY

The Fall meeting of the American Chemical Society will be held at the Bellevue-Stratford Hotel, Philadelphia, Pa., under the auspices of the Philadelphia Section, from Tuesday, Sept. 2 to Saturday, Sept. 6, 1919, inclusive.

Tuesday afternoon and evening will be occupied by a Council meeting and dinner.

Wednesday morning several addresses will be delivered notably that of Welcome by Hon. Joseph S. Mac Loughlin, Director of Supplies of Philadelphia; an address by Secretary of War, Newto D. Baker and one by a Navy Dep representative. Wednesday afterno will be the General Divisional Meeting at which many papers of interest will be delivered and discussed, Wednesday evening a smoker.

Thursday, 9:30 to 1 p. m. divisional meeting; 2 p. m. excursion to industrial establishments.

Friday the entire day will be devoted to presentation of various papers. At 7 p. m. a banquet will be given at Bellevue-Stratford.

Saturday a boat ride along the Delaware water front, passing Hog Island, etc., is tendered by the Delaware Section.

NATIONAL SAFETY COUNCIL TO MEET IN CLEVELAND

Some of the most important probems before American industry will be discussed in connection with the general subject of accident prevention at the Eighth Annual Safety Congress of the National Safety Council in Cleveland, October 1st to 4th.

The great bulk of the accident prevention talent of the country—160 scheduled speakers and approximately 3,000 men and women who direct the safety work of the nation's greatest industries—will come together for a four day exchange of ideas and experiences.

There will be four general sessions, four round tables, and 35 sectional meetings during the congress. As all the general sessions will open at 2 o'clock in the afternoon and the sectional meetings at 9:30 o'clock in the morning it will be possible for any one to attend all the general sessions and also all the sectional meetings for his particular industry.

The first general session will be devoted entirely to a discussion of employees representation under the following sub-heads: "Cooperation and Industrial Progress," "Labor Management and Collective Bargaining," "Practical Aspects of Employees' Representation" and "Employees' Representation from the standpoint of Organized Labor."

A. I. E. E. DIRECTORS' MEETING
August 12, 1919

The first meeting of the Board of Directors of the Institute for the administrative year beginning on August 1, 1919, was held at Institute headquarters New York, on Tuesday, August 12, at 3:00 p. m.

There were present: President Calvert Townley, New York; Past-President C. A. Adams, Cambridge, Mass.; Vice-Presidents A. M. Schoen, Atlanta, N. A. Carle, Newark, N. J.; Managers Charles S. Ruffner, W. A. Del Mar, W. I. Schlichter, L. F. Morehouse, New York, E. H. Martindale, Cleveland, Walter A. Hall, West Lynn, Mass.; Wilfred Sykes, Pittsburgh, G. Faccioli, Pittsfield, Mass.; L. E. Imlay, Niagara Falls; Treasurer George A. Hamilton, Elizabeth, N. J.; and Secretary F. L. Hutchinson, New York.

President Townley announced the appointment of committees for the administrative year beginning August 1, 1919, as published elsewhere in this issue of the PROCEEDINGS.

In accordance with the By-laws of the Edison Medal Committee, the Board elected from its own membership Messrs. G. Faccioli, Walter A. Hall, and Wilfred Sykes, to serve upon the Committee for the term of two years ending July 31, 1921.

Mr. Guido Semenza was reappointed Local Honorary Secretary for Italy, and Mr. Charles le Maistre was appointed Local Honorary Secretary for England, for the term of two years ending July 31, 1921.

The action of the Finance Committee in approving monthly bills amounting to $14,773.50, was ratified.

Reports were presented of meetings of the Board of Examiners held July 14 and August 6, 1919; upon the recommendation of the Board, the following action was taken upon pending applications: 17 Students were ordered enrolled; 126 applicants were elected to the grade of Associate; 7 applicants were elected to the grade of Member; 1 applicant was elected to the grade of Fellow; 26 applicants were transferred to the grade of Member; 5 applicants were transferred to the grade of Fellow.

Upon the recommendation of the Sections Committee, the organization of a Student Branch at the Engineering School of Milwaukee was authorized.

In addition to the above, many other

matters relating to important activities and the general policy of the Institute were discussed and in most cases were referred to various committees and officers for further consideration. Reference to these matters may be found in this and future issues of the PROCEEDINGS under suitable headings.

ANDREW CARNEGIE

At a joint meeting of representatives of the Founder Societies, the United Engineering Society and the Engineers Club, held on August 12th, the following resolutions were adopted regarding the death of Mr. Andrew Carnegie. Copies of these resolutions have been spread upon the records of the various societies represented and have been transmitted to the family of Mr. Carnegie:

Andrew Carnegie's death August 11, 1919, at Lenox, Massachusetts, brought to its close a career which greatly advanced all the engineering arts and sciences. By the introduction into the United States of the Bessemer process for the production of steel and by the establishment and development of steel plants, which became the greatest in the world, he made available for engineers the most useful modern material for engineering construction. In the successful conduct of many industrial enterprises, he amassed great wealth, the possession of which he came to regard with deep seriousness as a public trusteeship. He devoted himself to the distribution of large portions of his fortune to projects for the benefit of Mankind. He distributed his wealth not only in many directions, but also with the exercise of great widsom based on careful investigation. His munificence provided large funds for the building of a home for the great national engineering societies and many associate societies. He was an honorary member of the American Institute of Mining and Metallurgical Engineers and American Society of Mechanical Engineers. He was personally known and loved by many engineers. In view of these facts, be it

Resolved, That the American Societies of Civil, Mining, Metallurgical, Mechanical and Electrical Engineers, the United Engineering Society and the Engineers' Club, herein express to the family of Mr. Carnegie and record their sincere appreciation of the great contributions of Andrew Carnegie to the advancement of engineering, and of his friendly assistance in making possible beautiful homes for the Engineering Societies and the Engineers' Club, thus fostering the spirit of unity in the profession.

THE ENGINEER CORPS UNDER THE PROPOSED ARMY REORGANIZATION

The so-called "Army Reorganization Bill" now before Congress provides for a largely increased Corps of Engineers. The total engineer personnel under the Regular Army organization now provided by law is 12,933, while the bill now before the Senate Committee on Military Affairs authorizes an enrollment of 28,338. The reorganization scheme provides that the Chief of Engineers shall have the rank of Major General, whereas under the present law he is a Brigadier General. Two Brigadier Generals are provided and the number of colonels is increased from 23 to 43; lieutenant-colonels from 30 to 52; majors from 72 to 134; captains from 152 to 322, and first lieutenants from 148 to 431.

There is much speculation, inside as well as outside of the service, as to the source from which this largely increased personnel of engineer officers will be secured. It seems apparent that a large number of the newly created commissions must be filled through the Reserve Corps or otherwise. Unless some fundamental change is made in the method of selecting engineer officers from among West Point graduates a large proportion of the engineer officers in service will lack those exclusive qualifications which have heretofore characterized the Corps by reason of the fact that engineer officers are, under the present law, selected from West Point graduates who have attained the highest rank in academic studies.

It is reported that since the signing of the armistice about 1500 Regular Army officers have presented their resignations, and these include a number of engineer officers of the highest usefulness whose loss to the Corps will be severely felt. The Chief of Engineers in recent testimony before a committee of Congress commented upon the present low state of morale among

Regular Army officers and it has been assumed that he included in this catagory the officers of his own department, as well as those in others. In any event the situation is interesting from the point of view of the civilian engineer because unless some expedient is adopted, the nature of which is at present not quite clear, it may occur that the enlarged engineering program of the War Department may make it possible for duly qualified civilian engineers to render service to the country via the military route, even in time of peace.

NEW APPOINTMENTS AT MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Mr. W. H. Timbie, who is well known for his teaching in vocational subjects and for his important list of books relating to Electrical Engineering and Applied Electricity, has been appointed Associate Professor of Electrical Engineering in the Massachusetts Institute of Technology.

Mr. Timbie graduated from Williams College in 1901 with honors, being high in the list of Phi Beta Kappa. During his college course he prepared for teaching and shortly after graduation became a teacher of Applied Science at the Pratt Institute in Brooklyn. Upon the establishment of the Wentworth Institute in Boston he became Head of the Department of Applied Science in that Institute.

During the past year he has been Editor in Chief of the Committee on Education and Special Training in the United States War department at Washington.

Mr. Timbie is a Member of the American Institute of Electrical Engineers, has been active in the National Educational Association and has important memberships in other engineering and educational societies.

At the Massachusetts Institute of Technology his principal duty will be the supervision of the cooperative course in Electrical Engineering which is carried on in association with the General Electric Company.

Messrs. Frederick S. Dellenbaugh, Columbia University, 1910, Arthur L. Nelson, Massachusetts Institute of Technology, 1915, and F. B. Philbrick, Massachusetts Institute of Technology, 1918, have been appointed Instructors in Electrical Engineering at the Massachusetts Institute of Technology.

Mr. Dellenbaugh was a Captain of the Signal Corps in overseas service during the War. He graduated from the Electrical Engineering Course at Columbia, and has been in the employ of the Crocker Wheeler Manufacturing Company and the Westinghouse Electric and Manufacturing Company in the departments of Design and Commercial Engineering. His particular duties in his new appointment will be in the teaching of Dynamo Design and the Mechanical Applications of Electric Power. Mr. Dellenbaugh will also give a portion of his time to research along lines relating to electrical machinery.

Mr. Nelson graduated from the Electrical Engineering Course of the Massachusetts Institute of Technology. During the War he has been a Lieutenant in the Engineer Corps of the Navy with important work relating to construction of power plants and supply of power at the submarine base. After graduating he had experience with the C. H. Tenney Company in construction and operation of electric plants. Mr. Nelson's work will be instruction relating to Central Stations and Distribution Systems. He will also carry on some work as a consulting engineer.

Mr. Philbrick since graduating has been in the employ of the General Electric Company. His work at the Institute will be instruction in Electrical Measurements under the direction of Professor Laws and carrying on researches relating to electric circuits which Professor Laws has on hand.

ENGINEERING COUNCIL

APPOINTMENT OF ENGINEER ON INTERSTATE COMMERCE COMMISSION

The following letter has been addressed to President Wilson by J. Parke Channing, Chairman of Engineering Council, urging the appointment of an engineer for the vacancy on the Interstate Commerce Commission and setting forth the reasons for such an appointment:

The President,
The White House,
Washington, D. C.

Sir:

The transportation systems of our country are largely the creations of its professional Engineers. This statement can be made without disparagement to the statesmen, the financiers, the manufacturers, the lawyers, the educators, the mechanics, the laborers and many others, who, with the Engineers, have contributed to the development of transportation. Through all stages of preliminary exploration, final survey, construction, upkeep and operation, in financial management, and in adjustment of the relations of transportation to the public, the genius and knowledge of the Engineer are essential. Not only in technical physical matters, but also in determinations of policy, his contributions have supplemented and must ever supplement those of other men. These declarations hold good for all the carriers of commerce, by rail, by highway, by water, by pipe-line, by wire, or by air. Hence, it follows that the body established by the Government to regulate the commerce, the carriers and the ways of communication, embracing so many engineering features, should number among its nine members, men of engineering training and experience.

Engineering Council, being aware of a vacancy on the Interstate Commerce Commission, begs leave to request the Chief Executive that in filling this vacancy, he give earnest thought to the selection of a man who, to his other qualifications, adds the training and experience of an engineer familiar with transportation problems.

Engineer members wisely chosen would bring to the investigations and deliberations of the Interstate Commerce Commission not only technical knowledge of great value, but also experience in executive duties, a judicial attitude gained through the direction of work under contracts, minds of analytical habit, familiarity with costs of construction and operation, experience in dealing with employees of many vocations, and integrity of thought cultivated by that inescapable obedience to the laws of Nature involved in the practice of this profession. The Engineer's training fits him for that mode of thinking which is indispensable to impartiality of judgment. One important function of the Commission is valuation of public utilities and another is the determination of relationships and responsibilities of the management of such utilities to the public. No other body of men has given so extensive and so scientific consideration to these matters as have members of the Engineering Profession.

Council's purpose is not to further the interests of any individual or group, but solely to serve the Nation by strengthening one of its most important regulatory bodies. Upon the wisdom, intelligence and courage of this Commission depends in large measure the commercial welfare of the country. It is believed that the Engineering Profession can and should contribute to the country's well-being through the channel of membership in the Interstate Commerce Commission.

Very respectfully,
J. PARKE CHANNING
Chairman.

STRENGTHENING OF PATENT OFFICE

Proposed Legislation

The Patents Committee of Engineering Council has collaborated with the similar committee of National Research Council in developing a scheme for the improvement of the method of dealing with patents in this country. The staff of the Patent Office is itself actively engaged in this effort. Out of the report prepared by the National Research Council, and approved and adopted by Engineering Council as the report also of its Patents Committee, remedial legislation has taken form. Three bills have been introduced, known as H. R. 5011, a bill to make the Patent Office independent of the Department of the Interior or any other department, and to simplify the procedure of the Courts with reference to assessment of damages or profits for infringement of patents; H. R. 5012, a bill to establish a single Court of Patent Appeals; and H. R. 7010, a bill to increase the force and salaries in the Patent Office.

Chairman Charles A. Terry, of the Patents Committee, suggests that interested engineers write to their congressmen, urging the passage of these bills and so far as convenient, request their friends to do likewise.

REPORT OF DELEGATES TO FRANCE TO FOUNDER SOCIETIES

The delegation of American Engineers which visited France last winter at the invitation of the Congrés General du Génie Civil has submitted its report to the Engineering Societies which the delegates represented. The delegation was made up as follows:

Representing the A. S. C. E.: James F. Case, George F. Swain, Nelson P. Lewis, George W. Tillson, George W. Fuller and A. M. Hunt.

Representing the A. S. M. E.: Charles T. Main.

Representing the A. I. E. E.: Lewis B. Stilwell.

Representing the A. I. M. E.: E. G. Spilsbury.

The report covers the activities of the delegation from the time of its arrival in France, December 16, 1918 to January 18, 1919 when it embarked for its return home. The French engineering congress had held meetings in March, 1918, and presented a large number of papers, copies of which were studied by the delegation on the trip over. The delegates were therefore prepared to discuss the papers and to make recommendations to the congress on their arrival.

A great many French cities were visited by the delegates where engineering and manufacturing works were inspected, and trips were also made to the front where the principal battles of the war were fought.

As the result of its visit the delegation feels that it has gained a very good idea of the conditions in France and of the problems which confront that country. As a result of its discussions with the French engineers, the excursions made and a study of the reports of the French congress, the delegation was able to leave a preliminary report with the congress, which report has since been expanded, and further information added regarding American practise, at the request of the French engineers.

The report to the founder societies gives a general review of the subjects considered by the delegation and the proposed work of reconstruction. A synopsis of this report is contained in the addresses by members of the delegation at a joint meeting of the founder societies in New York, February 10, which were published in abstract in the March 1919 PROCEEDINGS.

The complete report is on file at Institute headquarters where it may be consulted at any time.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before September 30, 1919.

Abbott, R. L., Bloomfield, N. J.
Airey, F. J., Los Angeles, Cal.
Anderson, R. T., Philadelphia, Pa.
Bailey, E. L., Detroit, Mich.
Beiler, A. H., New York, N. Y.
Beymer, R. Alvin, (Member), Pittsfield, Mass.
Bischoff, H. W., Long Island City, N. Y.
Boothby, F. H., Portland, Ore.

Brainerd, Arthur A., Danbury, Conn.
Buell, W. G., Los Angeles, Cal.
Cobb. H. L., Philadelphia, Pa.
de Coutouly, G. C., New York, N. Y.
Foster, G. H., Rochester, N. Y.
Hix, D. G., Atlanta, Ga.
Hu, K. P., Schenectady, N. Y.
Husbands, R. H., Los Angeles, Cal.
Ides, X. D., New York City, N. Y.
Ishiyama, Tatsuo, Wilkinsburg, Pa.
Johnson, Roderick J., Flushing, N. Y.
King, I. C., Auburn, N. Y.
Knight, A. C., San Francisco, Cal.
Kuniansky, I., Atlanta, Ga.
Lawrence, George W., Toronto, Ontario.
Loomis, P. B., Springfield, Mass.
March, J. W., Akron, Ohio.
Matthews, Charles, Yosemite Valley, Cal.
McConnaughey, E. C., Atlanta, Ga.
McGalliard, D. C., Bethlehem, Pa.
McPherson, Ray Burdick, New York Mills, N. Y.
Michener, H., Los Angeles, Cal.
Morgan, F. M., Cortland, N. Y.
Moreley, Herbert M., Los Angeles, Cal.
Moudgal, N. N., Schenectady, N. Y.
Murrell, W. C., Charlotte, N. C.
Nash, J. C., Hamilton, Ont.
Nomura, I., Schenectady, N. Y.
Price, LeRoy F., Cleveland, Ohio.
Rainsford, C. A., Port Alice, Vancouver, B. C.
Reynolds, A. B., Schenectady, N. Y.
Robbins, F. J., Tacoma, Wash.
Robinson, E. H., Boston, Mass.
Rohman, H. D., (Member), New York, N. Y.
Shaw, S. F., Charcas, S. L. P., Mexico.
Simpson, R. H., W. Lynn, Mass.
Smith, I. F., Cincinnati, Ohio.
Stern, Morris, New York, N. Y.
Swensk, A. L., Arlington, N. J.
Tracy, E. P., Boston, Mass.
Wainwright, H., Sarnia, Ont.
Weisser, Chas. F., Lancaster, Pa.
Whitsit, L. A., (Member), Washington, D. C.
Wilkes, Frederick, (Member), Pittsburgh, Pa.
Wilson, Leon T., West Somerville, Mass.
Yoerg, August, New York, N. Y.
Total 54.

Foreign Applications

Aymerich, F. E., Mexico City, Mexico.
Boyce, B. A. M., Loughborough, Eng.
Cable, M., (Member), Wellington, N. Z.
Doyle, H. P., Yokohama, Japan.
Dunton, E. W., Singapore, S. S.
Echevarria, A. B., Rio Piedras, Porto Rico.
Fujita, Morio, Tokyo, Japan.
Gatland, H. C., Auckland, N. Z.
Grace, I. W., Wairarapa, N. Z.
Jones, J. W., Auckland, N. Z.
Margetts, Wm. Lester, (Member) Havana, Cuba.
Masumi, K., Fukuokaken, Japan.
Nimmo, H., (Member), Woolwich, London, S.E., Eng.
Parker, F. T., (Member), London, S.W., Eng.
Sekizawa, Sankichi, Fukukaken, Japan.
Simpson, Richard, (Member), Santiago, Chile.
Stevens, George C., Rio de Janeiro, Brazil.
Total 17.

ASSOCIATES ELECTED AUGUST 12, 1919

ARNOIS, CHARLES, Sales Distributor, Campbell Electric Co., Lynn, Mass.; res., 1309 E. Adams St., Syracuse, N. Y.

ARNOLD, ALFRED EDWARD, Chief Electrician, Oakland Motor Car Co.; res., 42 Green St., Pontiac, Mich.

*AUGUSTINE, R. W., Kellogg Switchboard & Supply Co., Chicago; res., 249 Thomas St., Oak Park, Ill.

AVINS, NATHAN, Testing of Electrical Machinery, Diehl Mfg. Co., Elizabethport, N. J.; res., 158 East 113th St., New York, N. Y.

AYMOND, WALTER E., Capt. Engineers, U. S. A.; Supt., Natchetoches Elec. & Water Works, Natchetoches, La.

BARRETT, JAMES E., Statistical Dept., San Joaquin Light & Power Corp., Fresno, Cal.

BERGER, PAUL, Asst. in Research Laboratory, Kellogg Switchboard & Supply Co.; res., 3544 W. 12th Place, Chicago, Ill.

Binion, W. H., Foreman, Electrical Dept., Eastman Kodak Co.; res., 374 Raines Park, Rochester, N. Y.

Binns, Arthur P., Asst. District Engineer, Hydro-Electric Department; res., 12 Bellevue Parade, New Town, Hobart, Tasmania.

Bond, John Milton, Head of Test Dept. Car Equipment Dept. Interborough Rapid Transit Co.; res., 596 Riverside Drive, New York, N. Y.

Bonner, James Shepherd, Long Line Engineer, Cumberland Tel. & Tel. Co., Nashville, Tenn.

Bremilst, Arthur F., Expert Armature Winder, 125 Armory St., Roxbury; res., 63 Lawrence St., Medford, Mass.

Broadwell, William Ernest, Transmission Engineer, Cumberland Tel. & Tel. Co., Nashville, Tenn.

Burleen, Oscar, Asst. Elec. Engineer, Elevator Supplies Co., Inc., Hoboken; res., 316 Forest St., Arlington, N. J.

Burt, Robert C., Research Laboratory, General Electric Co.; res., 22 Gillespie St., Schenectady, N. Y.

Call, George Richard, Treasurer, Call Bond and Mortgage Co., Sioux City, Iowa.

Castleman, David James, Greensboro, Ala.

Catlett, Robert Larkin, Electrician, E. I. du Pont de Nemours & Co., Dye Works, Deepwater; res., Stag Club, Carneys Point, N. J.

***Chestnut, Roy W.**, Waynoka, Oklahoma.

Collison, Alfred B., Traveling Salesman, Southern Electric Co., Baltimore; res., Bayonne Ave., Hamilton, Md.

Cook, Frederick Ernest, Motive Power Office, United Railroads of San Francisco, 1125 Fillimore St., San Francisco, Cal.

Cookingham, Edward H., Manager, Telephone & Electric Supply Co.; res., E. 2004, 12th Ave., Spokane, Wash.

***Cordes, Herbert A.**, Student University of Southern California; res., 3037 S. Vermont Ave., Los Angeles, Cal.

Cottrell, Lynn E., General Foreman, Elec. Construction, Submarine Boat Corp., Port Newark; res., 19 Eaton Place, E. Orange, N. J.

Cowgill, Miller Raymond, Supt., Fire Alarm Dept., Victor Talking Machine Co.; res., 108 N. 5th St., Camden, N. J.

Cunerty, Thomas Joseph, Engineer, Shewan Tomes & Co., 12 Broadway, New York, N. Y.

Cunningham, Frederick John, Asst. Div. Supt., Consumers Power Co., Mechanic & Trail Sts., Jackson, Mich.

Dale, W. Jocelyn E., Electrical Engineer, Compania Azucarera Elia, Ingenio "Elia" Elia., Camaguey; res., Apartado 2593, Havana, Cuba.

Daniel, William Robert, Chief Electrician, Radio, Navy Yard, New York; res., Naval Y. M. C. A., Brooklyn, N. Y.

***Dean, Harry**, Electrician, Bolsover Colliery Co., Mansfield, England.

De Lapp, Cyril A., Foreman, Ship Electrical Installation, Federal Shipbuilding Co., Kearny, N. J.; res., 152 Guernsey St., Brooklyn, N. Y.

Demmert, William Charles, Draftsman, American Cyanamid Co., New York, N. Y.; res., 119 Garrison Ave., Jersey City, N. J.

deVelazco, Joseph F., Distribution Engineer, Havana Electric Railway Light & Power Co., Havana, Cuba.

Dierken, Joseph Henry, Chief Electrician, The Capital Traction Co., 36th & M. Sts., N. W., Washington, D. C.

Doi, Kura, In charge of Engg. Dept., Suzuki & Company, 220 Broadway, New York, N. Y.

Driver, Edgar Thomas, Elec. Dept., The British Aluminum Co., Ltd., 60 Front St., Toronto, Ont.

Drummond, Ralph S., Asst. Chief Electrician, Morris & Company, Union Stock Yards; res., 7003 S. Green St., Chicago, Ill.

Elliott, Frederick Forester, Generating Station, London Elec. Supply Co., Ltd.; res., 46 Lansdowne Gardens, London S. W. 8, England.

Fearing, Justin L., Asst. Engineer, U. S. Patent Office, Washington, D. C.

Fink, Louis, Electrician, W. & A. Fletcher Co., Hoboken; res., 282 Forest St., Jersey City, N. J.

Flood, Armand A., Electrician, Eastman Kodak Co.; res., 126 Plymouth Ave. So., Rochester, N. Y.

Gift, Frank A., Division Electrician, Plant Dept., Western Union Tel. Co., 515 Bankers Investment Bldg., San Francisco, Cal.

*Gillespie, Leigh R., Telephone Engineer, Stromberg-Carlson Tel. Mfg. Co.; res., 431 Hayward Ave., Rochester, N. Y.

Gollos, Anatol, Electrical Engineer, Chicago Union Station Co.; res., 554 Belmont Ave., Chicago, Ill.

Green, John G., General Manager, Kentucky River Power Co., Hazard, Ky.

Gross, Walter Clay, Long Line Engineer, Cumberland Tel. & Tel. Co., Nashville, Tenn.

*Guimaraes, Ary de S. M., Engineer, "Prefeitura de Nictheroy", Caixa 545, Rio de Janeiro, Brazil, S. A.

Guterman, Herbert, Electrical Engineer, University of Paris, Paris, France; res., 53 W. 113th St., New York, N. Y.

Hagen, Carl, Chief Electrician, Portland Lumber Co.; res., 228 Meade St., Portland, Ore.

Hakanson, Joel, Engineering, Export Div., Edison Storage Battery Co.; res., 1935 Daly Ave., New York, N. Y.

Hamilton, William S. H., Railway Equipment Dept., General Electric Co.; res., 11 North Wendell Ave., Schenectady, N. Y.

Harries, Harry George, Industrial Division, Westinghouse Elec. & Mfg. Co., Chicago, Ill.

*Hodgson, Jonathan Archibald, Clerk, C. J. Hodgson & Co.; res., 714 Pine Ave., West, Montreal, Quebec.

*Hopkins, Ralph A., Sales Engineer, Westinghouse Elec. & Mfg. Co., Los Angeles; res., 681 Oakland Ave., Pasadena, Cal.

Huling, W. H., System Operator, Central Hudson Gas & Electric Co., 67 Montgomery St., Newburgh, N. Y.

Hulse, Leonard R., 1st Lieutenant Engineers, U. S. Army; res., Army & Navy Club, Newport News, Va.

Jobim, Adhemar de C., Cia General Electric do Brazil, Caiza do Correiro 109, Rio de Janeiro, Brazil, S. A.

Johnson, Oliver F., Engineer, The Pacific Tel. & Tel. Co., 502 Sheldon Bldg., San Francisco, Cal.

Kasahara, Kenjiro, Chief Engineer & Manager, Mitsubishi Shipbuilding Co., Ltd., 120 Broadway, New York, N. Y.

Keys, Albert H., Manager, Comanche Light & Power Co., Lawton, Oklahoma.

Kivlin, Joseph F., Appraisal Expert, U. S. A. P. Fabric Inspection Depot, Saylesville, R. I.; res., 55 Peck St., N. Attleboro, Mass.

*Klinefelter, Lee M., Electrical Draftsman, Navy Yard; res., 85 Lafayette Blvd., Norfolk, Va.

*Kramer, Andrew W., Ensign (E) U. S. N. R. F.; res., 7724 Lowe Ave., Chicago, Ill.

Laing, Norman B., Elec. Engineering Staff, Ford Motor Co., 73 Willis Ave. East, Detroit, Mich.

Lankford, E. A., Proprietor, Lankford Elec. & Battery Station; res., 605 Story St., Boone, Ia.

Laube, Otto T., Asst. in Research Laboratory, Kellogg Switchboard & Supply Co.; res., 3320 Beach Ave., Chicago, Ill.

Lauer, Henri, Engineering Dept., Bijur Motor Appliance Co., Hoboken, N. J.; res., 132 W. 85th St., New York, N. Y.

Lippincott, Donald K., Chief Engineer, Motor Protector Mfg. Co.; res., 1750 Mission St., San Francisco, Cal.

Livermore, Henry Wells, Dist. Manager, Electric Arc Cutting & Welding Co.; res., Hotel Lenox, Boston, Mass.

Locke, George Arthur, Electrical Engineer, Western Electric Co., 463 West St., New York, N. Y.

Logan, Henry, Technical Director, L. Sonneborn Sons, Inc.; res., 520 W. 175th St., New York, N. Y.

***Long, Charles Clarke**, 1st Lieut. Engineers; res., 899 Montauk Ave., New London, Conn.

***Ludden, Homer J.**, San Juan, Texas.

Malone, James Edward, Foreman, Interborough Rapid Transit Co., New York; res., 353 57th St., Brooklyn, N. Y.

***Mansfield, Laurence E.**, Automatic Attendant, Western Union Tel. Co.; res., 130 Peoples St., Atlanta, Ga.

Manwaring, Myron, Electrician, Salt Lake County, 427 Vine St., Murray, Utah.

***McAllister, George M.**, Engineering Dept., National Lamp Works of General Electric Co., Nela Park, E. Cleveland, Ohio.

McKechnie, Angus, Asst. Power Apparatus Specialist, Western Electric Co., 84 Marion St., Seattle, Wash.

McMillan, Henry W., Chief Electrician, C. B. & O. Shops, W. Burlington, Iowa.

***Miwa, T.**, Supt., California Vegetable Packing Co. Ltd., 1920 E. Vernon Ave., Los Angeles, Cal.

Nakao, Keiji, Chief Electrical Engineer & Manager of Engg. Dept., Furukawa Mining Co., Yayesucho Kojimachiku, Tokyo, Japan.

Nakasawa, George K., Engineering Dept. Ashio Copper Mines, Ashio, Japan.

Nevatt, Albert E., Inspector, B. & P. Coke Plant, Colorado Fuel & Iron Co.; res., 511 Broadway St., Pueblo, Colo.

O'Brien, Charles M., Supt., Minnesota Electric Light & Power Co., 112 E. Moses St., Cushing, Okla.

***Olson, Victor O.**, 75 New St., Naugatuck, Conn.

Park, Charles D., Asst. Meter Specialist, General Electric Co., 120 Broadway, New York, N. Y.

Pearson, Ernest Helmer, Erecting Engineer, Electric Machinery Co., Minneapolis, Minn.

***Perry, Arlington C.**, Designer, American Rolling Mill Co.; res., 124 S. Harrison Ave., Middletown, Ohio.

Peterson, Charles A., Electrician, Burnside Shops, Illinois Central R. R. 10934 Wabash Ave., Chicago, Ill.

Phelan, George Stanley, Supt. of Elec. Construction, Ideal Coated Paper Co., Brookfield, Mass.

Priddle, William Henry, Draftsman, Toronto Hydro-Electric System; res., 1161 Ossington Ave., Toronto, Ontario.

***Purple, Jay Curtis**, Newark Valley, N. Y.

Pyster, John Neal, Chief Engineer, Raritan Copper Works, Perth Amboy N. J.

Rademacher, William Henry, Engineer in Service Office, Crocker-Wheeler Co., Ampere; res., 216 Weequahic Ave., Newark, N. J.

Rees, John B., Div. Equipment Engineer, Cumberland Tel. & Tel. Co., Nashville, Tenn.

Roe, Fremont Lee, 57th & Grand Ave., Wauwatosa, Wis.

***Roedel, William G.**, Electrical Tester, American Bosch Magneto Corp., Springfield, Mass.

Rogers, Frederick P., Major, Signal Corps. U. S. A., Peoples Bldg., Charleston, S. C.

Ryan, Francis M., Student in Elec. Engg., Univ. of Washington, Seattle, Wash.

Sadler, Ernest K., Dist. Supt., Nevada Valleys Power Co., Battle Mountain, Nevada.

Sauer, Louis B., Chief Inspector, Kellogg Switchboard & Supply Co., Chicago; res., Western Springs, Ill.

Schulz, Paul H., Chief Electrician of Street Lighting, Bureau of Illumination Service, City Hall, Milwaukee, Wis.

Seeley, Charles G., Manager, Melbourne Office, Australian General Electric Co., Queen & Little Collins St., Melbourne, Aus.

Shank, L. D., Manager & Supt., Municipal Light & Water Works, Centerville, Md.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its regular monthly meeting, held on August 6, 1919, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

Morehead, John M., Consulting Engineer, New York, N. Y.

To Grade of Member

Davis, Archibald, Jr., Senior Lieut., U. S. N. R. F., St. Louis, Mo.

Seeger, Edwin W., Electrical Engineer, Cutler-Hammer Mfg. Co., Milwaukee, Wis.

Thompson, William J., Member of firm, Thompson-Levering Co., Philadelphia, Pa.

Tremaine, A. Raymond, Manager and Chief Engineer, Depew & Lancaster Light, Power & Conduit Co., Lancaster, N. Y.

STUDENTS ENROLLED AUGUST 12, 1919

10440 Robinson, H. E., Clarkson Coll. of Tech.
10441 Kimball, H. R., Worcester Poly. Inst.
10442 Hilderbrandt, P. J., N. Y. Elec. School.
10443 Thompson, I. D., Clarkson School of Tech.
10444 Benscheidt, N. H., Univ. of Kansas.
10445 Anderson, H. C., Sheffield Scientific School.
10446 Langdon, G. G., State Coll. of Washington.
10447 Carlson, C. O., Sheffield Scientific School.
10448 Haugh, H. A., Sheffield Scientific School.
10449 Osgyani, G. L., Sheffield Scientific School.
10450 Schmidt, H., Brooklyn Poly. Inst.
10351 Valldejuby, R. R., J. Y. Elec. School.
10452 Erb, H. G., Penn. State Coll.
10453 Lutsey, S. F., Casino Tech. Night School.
10454 Reid, K. M., Cornell Univ.
10455 Thakkur, K. B., Cornell Univ.
10456 Wise, E. M., Univ. of Wis.
Total 17

PERSONAL

Sidney W. Farnsworth recently returned from his duties as Associate Scientific Attaché at the American Embassy, London. He is now associated with Mark Manufacturing Co., Chicago, as Assistant to the Manager of the Evanston plant.

D. C. Hopper has accepted a position with the Newport News and Hampton Railway, Gas and Electric Company. Previous to the outbreak of the war Mr. Hopper was with the Commonwealth Edison Company of Chicago as Assistant Superintendent of underground cable system and since that time has been in charge of the electric distribution and signal systems of the American International Shipbuilding Corporation.

Dwight P. Robinson and Company, New York, have been awarded a contract by the Duquesne Lighting Company of Pittsburgh, to design and construct a power station at Cheswick, near Pittsburgh, to have an ultimate capacity of 300,000 kw. of which one unit of 60,000 kw. is to be installed initially.

David S. Wegg, Jr. has accepted a position as testing engineer for the Isko Company, Chicago, Ill., manufacturers of electric refrigerating machines. Mr. Wegg has been serving as assistant to the Contracting Officer, Chicago District, Ordnance Dept., U. S. A.

C. J. Berry, for the last six years with the National Lamp Works of the General Electric Company, Cleveland, has accepted a position as electrical engineer with Brandt and Fouilleret, Paris, France. Mr. Berry served as First Lieutenant in the U. S. Air Service in the A. E. F.

ENGINEERING SERVICE BULLETIN

Opportunities.—The Institute, is particularly anxious to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in this BULLETIN. The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Services Available.—Under this heading brief announcements (not more than fifty words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office files.

Note.—Copy for publication in the BULLETIN should reach the Secretary's office not later than the 20th of the month if publication in the following issue is desired.

All replies to either "Opportunities" or "Services Available" announcements should be addressed to the number indicated in each case, and mailed to Institute headquarters.

Engineering Societies Employment Bureau.—This is a joint bureau under the auspices of the Engineering Council. The Institute's employment service is coordinated with that of the joint bureau.

OPPORTUNITIES FOR SERVICE

V-556. Well known electrical firm expanding its export service requires translator to rewrite electro-technical English into technical Spanish chiefly for publications to be distributed in South America. Engineer preferred. Advancement, etc., will depend on ability and expansion of the trade. State qualifications, experience and salary expected.

V-557. A college graduate with some practical or teaching experience is wanted for the position of instructor in the electrical engineering department of a well known college near New York City. Salary $1200 for about nine months' work.

V-558. Assistant to superintendent of power. Technical graduate in mechanical engineering, 1918 or 1919.

V-559. Technical engineers for steam plant betterment work. Men would be required to advise management and coach operating force in economical operation. Tact, willingness to work and combustion experience (oil and gas firing) required. Location southwest. Salary depends on qualifications.

V-560. A graduate of three or four years' standing, age 28 to 30, for general work as assistant engineer in a 100,000 h. p. hydroelectric development. This position offers an early opportunity for advancement to assistant having direct supervision of operation and maintenance followed by responsible charge of development.

V-561. Young man, single, recently graduated from technical school for inspecting and testing electrical apparatus, also general laboratory work. General Electric Company test department experience preferred. Good scholastic record and personality important.

V-562. A trained mechanical engineer with a knowledge of machinery and machine parts. Preference will be given to the man who is particularly qualified from the purely technical side. The use of a good deal of higher mathematics will be necessary in this work. The opportunity offered is that of assistant to the head of the engineering division of a large corporation selling to the machinery field. Salary will be commensurate with demonstrated ability.

Instrument Repairman (Electrical) Wanted for the Panama Canal—$197.60 month. Must be capable of testing, repairing and installing all types of watt-hour meters, and indicating and curve drawing instruments, both alternating and direct current in portable and switchboard types. Also instrument maker, $1.05 hour, thoroughly experienced on engineering instruments. Must be American citizens, final papers, under 50 years of age, in good health. Free steamship transportation from New York or New Orleans, wages beginning date of sailing. Write "Chief of Office, The Panama Canal, Washington, D. C."

The United States Civil Service Commission announces open competitive examinations for the positions of Electrical Engineer (male) $2,400 to $3,600 a year, and Assistant Electrical Engineer (male) $1,800 to $2,400 a year. Vacancies are in the Signal Service at Large, Washington, D. C.

Published monthly by the A. I. E. E. at 33 West 39th Street, New York.

Under the Auspices of the Meetings and Papers Committee.

GEORGE R. METCALFE, Editor.

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXVIII SEPTEMBER, 1919 Number 9

THE PACIFIC COAST CONVENTION

The eighth annual Pacific Coast Convention will be held in Los Angeles, California, September 18-20, 1919, under the auspices of the Los Angeles Section. The program as arranged by the local committees insures important technical sessions as well as many pleasant social features.

The technical program is as follows:

1. *California 220-Kv., 1100-Mile, 1,500,000-Kw. Transmission Bus*, by R. W. Sorensen, Professor of Electrical Engineering, Throop College of Technology, and H. H. Cox and G. E. Armstrong, of the Southern California Edison Company.
2. *Predetermination of Synchronous Phase Modifier Performance*, by Hubert V. Carpenter, Dean of Mechanic Arts and Engineering, State College of Washington, Pullman, Wash.
3. *Theory of Probabilities Applied to Failures of Suspension Insulators*, by L. M. Klauber, of San Diego Consolidated Gas and Electric Company.
4. *Order and Amplitude of Harmonics in Voltage Wave Forms with Indicating Instruments*, by Leslie F. Curtis, Assistant Professor of Electrical Engineering, University of Washington.
5. *Symposium on Operating Difficulties.* This symposium will consist of a number of valuable short papers from many sources, covering various operating troubles.

Paper No. 1 appears in this issue of the PROCEEDINGS and papers Nos. 2, 3 and 4, in the August PROCEEDINGS. The Symposium papers will be read from manuscript.

The Entertainment Committee promises a splendidly arranged program, to be announced at the convention, of special interest to ladies, who are cordially invited to attend.

JOINT A. I. E. E. AND I. R. E. MEETING IN NEW YORK

A joint meeting of the American Institute of Electrical Engineers and the Institute of Radio Engineers will be held in the Auditorium of the Engineering Societies Building, 33 West 39th Street, New York, on October 1, 1919, at 8:15 p. m.

Three papers will be presented as follows:

1. *Trans-Oceanic Radio Telegraphy*, by E. F. W. Alexanderson, of the General Electric Co.
2. *Telephone Repeaters*, by F. B. Jewett and B. Gherardi, both of the Western Electric Co.
3. *Principles of Radio Transmission and Reception with Antenna and Coil Aerials*, by J. H. Dellinger, of the Bureau of Standards.

JOINT MEETING IN PHILADELPHIA

October 10-11, 1919

A joint meeting of the American Institute of Electrical Engineers and the American Physical Society will be held in Philadelphia, at the Bellevue-Stratford Hotel, on Friday and Saturday, October 10-11, 1919.

The technical sessions on Friday will be held in the Clover Room of the Bellevue-Stratford and the subscription dinner Friday evening in the Stratford Room. The technical sessions on Saturday will be held at the works of the Leeds and Northrup Company, where a complimentary luncheon will be served by the company.

The program is as follows:

Friday, 9:00 a. m.
Session of the Physical Society

Atomic Structure. Paper by P. W. Bridgeman and Irving Langmuir. Discussion by Saul Dushman and others. It is intended to make this interesting to engineers as well as physicists.

Friday, 2:30 p. m.
Session of the A. I. E. E.

1. *The Arrangement of Atoms in Metals*, by Dr. A. W. Hull of the General Electric Research Laboratory. An X-ray study of crystal structures, a demonstration with models of crystals will be shown. (Written for engineers).
2. *The Oscillating Vacuum Tube as a Generator of Electrical Power*, by Professors J. H. Morecroft and H. T. Friis, both of Columbia University. Lantern slides of oscillograph records.
3. *Electromagnetic Induction*, by Dr. J. S. Barnett of the Carnegie Institute, Washington.
4. *Piezo Electrical Effect*, by Dr. A. M. Nichols of the Western Electric Company. (Demonstration).

Friday, 6-00 p.m.
Subscription Dinner

Five minute talks by presidents of the two societies.

Friday, 8:00 p.m.

Technical papers by Prof. H. A. Bumstead of Yale University, and Mr. J. J. Carty, Vice-president of the American Telephone and Telegraph Company.

Saturday Morning
Session of the Physical Society

Inspection of the Leeds and Northrup Plant.

Two semi-technical papers by the Research Laboratories of Leeds and Northrup Company.

Saturday Noon

Complimentary Luncheon by the Leeds and Northrup Company.

Automobile ride around Germantown.

Saturday Afternoon

Regular Physical Society papers.

There will probably be opportunity for technical excursions to the Welsbach factory or a steamer ride on the Delaware River to Chester at 10:30 Friday morning. The steamer ride will be available Saturday morning also.

PHILADELPHIA MEETING OF AMERICAN CHEMICAL SOCIETY

The Fall meeting of the American Chemical Society will be held at the Bellevue-Stratford Hotel, Philadelphia, Pa., under the auspices of the Philadelphia Section, from Tuesday, Sept. 2 to Saturday, Sept. 6, 1919, inclusive.

Tuesday afternoon and evening will be occupied by a Council meeting and dinner.

Wednesday morning several addresses will be delivered notably that of Welcome by Hon. Joseph S. Mac Loughlin, Director of Supplies of Philadelphia; an address by Secretary of War, Newto D. Baker and one by a Navy Dep representative. Wednesday afterno will be the General Divisional Meeting at which many papers of interest will be delivered and discussed, Wednesday evening a smoker.

Thursday, 9:30 to 1 p. m. divisional meeting; 2 p. m. excursion to industrial establishments.

Friday the entire day will be devoted to presentation of various papers. At 7 p. m. a banquet will be given at Bellevue-Stratford.

Saturday a boat ride along the Delaware water front, passing Hog Island, etc., is tendered by the Delaware Section.

NATIONAL SAFETY COUNCIL TO MEET IN CLEVELAND

Some of the most important probems before American industry will be discussed in connection with the general subject of accident prevention at the Eighth Annual Safety Congress of the National Safety Council in Cleveland, October 1st to 4th.

The great bulk of the accident prevention talent of the country—160 scheduled speakers and approximately 3,000 men and women who direct the safety work of the nation's greatest industries—will come together for a four day exchange of ideas and experiences.

There will be four general sessions, four round tables, and 35 sectional meetings during the congress. As all the general sessions will open at 2 o'clock in the afternoon and the sectional meetings at 9:30 o'clock in the morning it will be possible for any one to attend all the general sessions and also all the sectional meetings for his particular industry.

The first general session will be devoted entirely to a discussion of employees representation under the following sub-heads: "Cooperation and Industrial Progress," "Labor Management and Collective Bargaining," "Practical Aspects of Employees' Representation" and "Employees' Representation from the standpoint of Organized Labor."

A. I. E. E. DIRECTORS' MEETING
August 12, 1919

The first meeting of the Board of Directors of the Institute for the administrative year beginning on August 1, 1919, was held at Institute headquarters New York, on Tuesday, August 12, at 3:00 p. m.

There were present: President Calvert Townley, New York; Past-President C. A. Adams, Cambridge, Mass.; Vice-Presidents A. M. Schoen, Atlanta, N. A. Carle, Newark, N. J.; Managers Charles S. Ruffner, W. A. Del Mar, W. I. Schlichter, L. F. Morehouse, New York, E. H. Martindale, Cleveland, Walter A. Hall, West Lynn, Mass.; Wilfred Sykes, Pittsburgh, G. Faccioli, Pittsfield, Mass.; L. E. Imlay, Niagara Falls; Treasurer George A. Hamilton, Elizabeth, N. J.; and Secretary F. L. Hutchinson, New York.

President Townley announced the appointment of committees for the administrative year beginning August 1, 1919, as published elsewhere in this issue of the PROCEEDINGS.

In accordance with the By-laws of the Edison Medal Committee, the Board elected from its own membership Messrs. G. Faccioli, Walter A. Hall, and Wilfred Sykes, to serve upon the Committee for the term of two years ending July 31, 1921.

Mr. Guido Semenza was reappointed Local Honorary Secretary for Italy, and Mr. Charles le Maistre was appointed Local Honorary Secretary for England, for the term of two years ending July 31, 1921.

The action of the Finance Committee in approving monthly bills amounting to $14,773.50, was ratified.

Reports were presented of meetings of the Board of Examiners held July 14 and August 6, 1919; upon the recommendation of the Board, the following action was taken upon pending applications: 17 Students were ordered enrolled; 126 applicants were elected to the grade of Associate; 7 applicants were elected to the grade of Member; 1 applicant was elected to the grade of Fellow; 26 applicants were transferred to the grade of Member; 5 applicants were transferred to the grade of Fellow.

Upon the recommendation of the Sections Committee, the organization of a Student Branch at the Engineering School of Milwaukee was authorized.

In addition to the above, many other

matters relating to important activities and the general policy of the Institute were discussed and in most cases were referred to various committees and officers for further consideration. Reference to these matters may be found in this and future issues of the PROCEEDINGS under suitable headings.

ANDREW CARNEGIE

At a joint meeting of representatives of the Founder Societies, the United Engineering Society and the Engineers Club, held on August 12th, the following resolutions were adopted regarding the death of Mr. Andrew Carnegie. Copies of these resolutions have been spread upon the records of the various societies represented and have been transmitted to the family of Mr. Carnegie:

> Andrew Carnegie's death August 11, 1919, at Lenox, Massachusetts, brought to its close a career which greatly advanced all the engineering arts and sciences. By the introduction into the United States of the Bessemer process for the production of steel and by the establishment and development of steel plants, which became the greatest in the world, he made available for engineers the most useful modern material for engineering construction. In the successful conduct of many industrial enterprises, he amassed great wealth, the possession of which he came to regard with deep seriousness as a public trusteeship. He devoted himself to the distribution of large portions of his fortune to projects for the benefit of Mankind. He distributed his wealth not only in many directions, but also with the exercise of great widsom based on careful investigation. His munificence provided large funds for the building of a home for the great national engineering societies and many associate societies. He was an honorary member of the American Institute of Mining and Metallurgical Engineers and American Society of Mechanical Engineers. He was personally known and loved by many engineers. In view of these facts, be it
>
> *Resolved*, That the American Societies of Civil, Mining, Metallurgical, Mechanical and Electrical Engineers, the United Engineering Society and the Engineers' Club, herein express to the family of Mr. Carnegie and record their sincere appreciation of the great contributions of Andrew Carnegie to the advancement of engineering, and of his friendly assistance in making possible beautiful homes for the Engineering Societies and the Engineers' Club, thus fostering the spirit of unity in the profession.

THE ENGINEER CORPS UNDER THE PROPOSED ARMY REORGANIZATION

The so-called "Army Reorganization Bill" now before Congress provides for a largely increased Corps of Engineers. The total engineer personnel under the Regular Army organization now provided by law is 12,933, while the bill now before the Senate Committee on Military Affairs authorizes an enrollment of 28,338. The reorganization scheme provides that the Chief of Engineers shall have the rank of Major General, whereas under the present law he is a Brigadier General. Two Brigadier Generals are provided and the number of colonels is increased from 23 to 43; lieutenant-colonels from 30 to 52; majors from 72 to 134; captains from 152 to 322, and first lieutenants from 148 to 431.

There is much speculation, inside as well as outside of the service, as to the source from which this largely increased personnel of engineer officers will be secured. It seems apparent that a large number of the newly created commissions must be filled through the Reserve Corps or otherwise. Unless some fundamental change is made in the method of selecting engineer officers from among West Point graduates a large proportion of the engineer officers in service will lack those exclusive qualifications which have heretofore characterized the Corps by reason of the fact that engineer officers are, under the present law, selected from West Point graduates who have attained the highest rank in academic studies.

It is reported that since the signing of the armistice about 1500 Regular Army officers have presented their resignations, and these include a number of engineer officers of the highest usefulness whose loss to the Corps will be severely felt. The Chief of Engineers in recent testimony before a committee of Congress commented upon the present low state of morale among

Regular Army officers and it has been assumed that he included in this catagory the officers of his own department, as well as those in others. In any event the situation is interesting from the point of view of the civilian engineer because unless some expedient is adopted, the nature of which is at present not quite clear, it may occur that the enlarged engineering program of the War Department may make it possible for duly qualified civilian engineers to render service to the country via the military route, even in time of peace.

NEW APPOINTMENTS AT MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Mr. W. H. Timbie, who is well known for his teaching in vocational subjects and for his important list of books relating to Electrical Engineering and Applied Electricity, has been appointed Associate Professor of Electrical Engineering in the Massachusetts Institute of Technology.

Mr. Timbie graduated from Williams College in 1901 with honors, being high in the list of Phi Beta Kappa. During his college course he prepared for teaching and shortly after graduation became a teacher of Applied Science at the Pratt Institute in Brooklyn. Upon the establishment of the Wentworth Institute in Boston he became Head of the Department of Applied Science in that Institute.

During the past year he has been Editor in Chief of the Committee on Education and Special Training in the United States War department at Washington.

Mr. Timbie is a Member of the American Institute of Electrical Engineers, has been active in the National Educational Association and has important memberships in other engineering and educational societies.

At the Massachusetts Institute of Technology his principal duty will be the supervision of the cooperative course in Electrical Engineering which is carried on in association with the General Electric Company.

Messrs. Frederick S. Dellenbaugh, Columbia University, 1910, Arthur L. Nelson, Massachusetts Institute of Technology, 1915, and F. B. Philbrick, Massachusetts Institute of Technology, 1918, have been appointed Instructors in Electrical Engineering at the Massachusetts Institute of Technology.

Mr. Dellenbaugh was a Captain of the Signal Corps in overseas service during the War. He graduated from the Electrical Engineering Course at Columbia, and has been in the employ of the Crocker Wheeler Manufacturing Company and the Westinghouse Electric and Manufacturing Company in the departments of Design and Commercial Engineering. His particular duties in his new appointment will be in the teaching of Dynamo Design and the Mechanical Applications of Electric Power. Mr. Dellenbaugh will also give a portion of his time to research along lines relating to electrical machinery.

Mr. Nelson graduated from the Electrical Engineering Course of the Massachusetts Institute of Technology. During the War he has been a Lieutenant in the Engineer Corps of the Navy with important work relating to construction of power plants and supply of power at the submarine base. After graduating he had experience with the C. H. Tenney Company in construction and operation of electric plants. Mr. Nelson's work will be instruction relating to Central Stations and Distribution Systems. He will also carry on some work as a consulting engineer.

Mr. Philbrick since graduating has been in the employ of the General Electric Company. His work at the Institute will be instruction in Electrical Measurements under the direction of Professor Laws and carrying on researches relating to electric circuits which Professor Laws has on hand.

ENGINEERING COUNCIL

APPOINTMENT OF ENGINEER ON INTERSTATE COMMERCE COMMISSION

The following letter has been addressed to President Wilson by J. Parke Channing, Chairman of Engineering Council, urging the appointment of an engineer for the vacancy on the Interstate Commerce Commission and setting forth the reasons for such an appointment:

The President,
The White House,
Washington, D. C.

Sir:

The transportation systems of our country are largely the creations of its professional Engineers. This statement can be made without disparagement to the statesmen, the financiers, the manufacturers, the lawyers, the educators, the mechanics, the laborers and many others, who, with the Engineers, have contributed to the development of transportation. Through all stages of preliminary exploration, final survey, construction, upkeep and operation, in financial management, and in adjustment of the relations of transportation to the public, the genius and knowledge of the Engineer are essential. Not only in technical physical matters, but also in determinations of policy, his contributions have supplemented and must ever supplement those of other men. These declarations hold good for all the carriers of commerce, by rail, by highway, by water, by pipe-line, by wire, or by air. Hence, it follows that the body established by the Government to regulate the commerce, the carriers and the ways of communication, embracing so many engineering features, should number among its nine members, men of engineering training and experience.

Engineering Council, being aware of a vacancy on the Interstate Commerce Commission, begs leave to request the Chief Executive that in filling this vacancy, he give earnest thought to the selection of a man who, to his other qualifications, adds the training and experience of an engineer familiar with transportation problems.

Engineer members wisely chosen would bring to the investigations and deliberations of the Interstate Commerce Commission not only technical knowledge of great value, but also experience in executive duties, a judicial attitude gained through the direction of work under contracts, minds of analytical habit, familiarity with costs of construction and operation, experience in dealing with employees of many vocations, and integrity of thought cultivated by that inescapable obedience to the laws of Nature involved in the practice of this profession. The Engineer's training fits him for that mode of thinking which is indispensable to impartiality of judgment. One important function of the Commission is valuation of public utilities and another is the determination of relationships and responsibilities of the management of such utilities to the public. No other body of men has given so extensive and so scientific consideration to these matters as have members of the Engineering Profession.

Council's purpose is not to further the interests of any individual or group, but solely to serve the Nation by strengthening one of its most important regulatory bodies. Upon the wisdom, intelligence and courage of this Commission depends in large measure the commercial welfare of the country. It is believed that the Engineering Profession can and should contribute to the country's well-being through the channel of membership in the Interstate Commerce Commission.

Very respectfully,
J. Parke Channing
Chairman.

STRENGTHENING OF PATENT OFFICE

Proposed Legislation

The Patents Committee of Engineering Council has collaborated with the similar committee of National Research Council in developing a scheme for the improvement of the method of dealing with patents in this country. The staff of the Patent Office is itself actively engaged in this effort. Out of the report prepared by the National Research Council, and approved and adopted by Engineering Council as the report also of its Patents Committee, remedial legislation has taken form. Three bills have been introduced, known as H. R. 5011, a bill to make the Patent Office independent of the Department of the Interior or any other department, and to simplify the procedure of the Courts with reference to assessment of damages or profits for infringement of patents; H. R. 5012, a bill to establish a single Court of Patent Appeals; and H. R. 7010, a bill to increase the force and salaries in the Patent Office.

Chairman Charles A. Terry, of the Patents Committee, suggests that interested engineers write to their congressmen, urging the passage of these bills and so far as convenient, request their friends to do likewise.

REPORT OF DELEGATES TO FRANCE TO FOUNDER SOCIETIES

The delegation of American Engineers which visited France last winter at the invitation of the Congrés General du Génie Civil has submitted its report to the Engineering Societies which the delegates represented. The delegation was made up as follows:

Representing the A. S. C. E.: James F. Case, George F. Swain, Nelson P. Lewis, George W. Tillson, George W. Fuller and A. M. Hunt.

Representing the A. S. M. E.: Charles T. Main.

Representing the A. I. E. E.: Lewis B. Stilwell.

Representing the A. I. M. E.: E. G. Spilsbury.

The report covers the activities of the delegation from the time of its arrival in France, December 16, 1918 to January 18, 1919 when it embarked for its return home. The French engineering congress had held meetings in March, 1918, and presented a large number of papers, copies of which were studied by the delegation on the trip over. The delegates were therefore prepared to discuss the papers and to make recommendations to the congress on their arrival.

A great many French cities were visited by the delegates where engineering and manufacturing works were inspected, and trips were also made to the front where the principal battles of the war were fought.

As the result of its visit the delegation feels that it has gained a very good idea of the conditions in France and of the problems which confront that country. As a result of its discussions with the French engineers, the excursions made and a study of the reports of the French congress, the delegation was able to leave a preliminary report with the congress, which report has since been expanded, and further information added regarding American practise, at the request of the French engineers.

The report to the founder societies gives a general review of the subjects considered by the delegation and the proposed work of reconstruction. A synopsis of this report is contained in the addresses by members of the delegation at a joint meeting of the founder societies in New York, February 10, which were published in abstract in the March 1919 PROCEEDINGS.

The complete report is on file at Institute headquarters where it may be consulted at any time.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before September 30, 1919.

Abbott, R. L., Bloomfield, N. J.
Airey, F. J., Los Angeles, Cal.
Anderson, R. T., Philadelphia, Pa.
Bailey, E. L., Detroit, Mich.
Beiler, A. H., New York, N. Y.
Beymer, R. Alvin, (Member), Pittsfield, Mass.
Bischoff, H. W., Long Island City, N. Y.
Boothby, F. H., Portland, Ore.

Brainerd, Arthur A., Danbury, Conn.
Buell, W. G., Los Angeles, Cal.
Cobb. H. L., Philadelphia, Pa.
de Coutouly, G. C., New York, N. Y.
Foster, G. H., Rochester, N. Y.
Hix, D. G., Atlanta, Ga.
Hu, K. P., Schenectady, N. Y.
Husbands, R. H., Los Angeles, Cal.
Ides, X. D., New York City, N. Y.
Ishiyama, Tatsuo, Wilkinsburg, Pa.
Johnson, Roderick J., Flushing, N. Y.
King, I. C., Auburn, N. Y.
Knight, A. C., San Francisco, Cal.
Kuniansky, I., Atlanta, Ga.
Lawrence, George W., Toronto,Ontario.
Loomis, P. B., Springfield, Mass.
March, J. W., Akron, Ohio.
Matthews, Charles,YosemiteValley,Cal.
McConnaughey, E. C., Atlanta, Ga.
McGalliard, D. C., Bethlehem, Pa.
McPherson, Ray Burdick, New York Mills, N. Y.
Michener, H., Los Angeles, Cal.
Morgan, F. M., Cortland, N. Y.
Moreley, Herbert M., Los Angeles, Cal.
Moudgal, N. N., Schenectady, N. Y.
Murrell, W. C., Charlotte, N. C.
Nash, J. C., Hamilton, Ont.
Nomura, I., Schenectady, N. Y.
Price, LeRoy F., Cleveland, Ohio.
Rainsford, C. A., Port Alice, Vancouver, B. C.
Reynolds, A. B., Schenectady, N. Y.
Robbins, F. J., Tacoma, Wash.
Robinson, E. H., Boston, Mass.
Rohman, H. D., (Member), New York, N. Y.
Shaw, S. F., Charcas, S. L. P., Mexico.
Simpson, R. H., W. Lynn, Mass.
Smith, I. F., Cincinnati, Ohio.
Stern, Morris, New York, N. Y.
Swensk, A. L., Arlington, N. J.
Tracy, E. P., Boston, Mass.
Wainwright, H., Sarnia, Ont.
Weisser, Chas. F., Lancaster, Pa.
Whitsit, L. A., (Member), Washington, D. C.
Wilkes, Frederick, (Member), Pittsburgh, Pa.
Wilson, Leon T., West Somerville, Mass.
Yoerg, August, New York, N. Y.
Total 54.

Foreign Applications

Aymerich, F. E., Mexico City, Mexico.
Boyce, B. A. M., Loughborough, Eng.
Cable, M., (Member), Wellington, N. Z.
Doyle, H. P., Yokohama, Japan.
Dunton, E. W., Singapore, S. S.
Echevarria, A. B., Rio Piedras, Porto Rico.
Fujita, Morio, Tokyo, Japan.
Gatland, H. C., Auckland, N. Z.
Grace, I. W., Wairarapa, N. Z.
Jones, J. W., Auckland, N. Z.
Margetts, Wm. Lester, (Member) Havana, Cuba.
Masumi, K., Fukuokaken, Japan.
Nimmo, H., (Member), Woolwich, London, S.E., Eng.
Parker, F. T., (Member), London, S.W., Eng.
Sekizawa, Sankichi, Fukukaken, Japan.
Simpson, Richard, (Member), Santiago, Chile.
Stevens, George C., Rio de Janeiro, Brazil.
Total 17.

ASSOCIATES ELECTED AUGUST 12, 1919

ARNOIS, CHARLES, Sales Distributor, Campbell Electric Co., Lynn, Mass.; res., 1309 E. Adams St., Syracuse, N. Y.

ARNOLD, ALFRED EDWARD, Chief Electrician, Oakland Motor Car Co.; res., 42 Green St., Pontiac, Mich.

*AUGUSTINE, R. W., Kellogg Switchboard & Supply Co., Chicago; res., 249 Thomas St., Oak Park, Ill.

AVINS, NATHAN, Testing of Electrical Machinery, Diehl Mfg. Co., Elizabethport, N. J.; res., 158 East 113th St., New York, N. Y.

AYMOND, WALTER E., Capt. Engineers, U. S. A.; Supt., Natchetoches Elec. & Water Works, Natchetoches, La.

BARRETT, JAMES E., Statistical Dept., San Joaquin Light & Power Corp., Fresno, Cal.

BERGER, PAUL, Asst. in Research Laboratory, Kellogg Switchboard & Supply Co.; res., 3544 W. 12th Place, Chicago, Ill.

BINION, W. H., Foreman, Electrical Dept., Eastman Kodak Co.; res., 374 Raines Park, Rochester, N. Y.

BINNS, ARTHUR P., Asst. District Engineer, Hydro-Electric Department; res., 12 Bellevue Parade, New Town, Hobart, Tasmania.

BOND, JOHN MILTON, Head of Test Dept. Car Equipment Dept. Interborough Rapid Transit Co.; res., 596 Riverside Drive, New York, N. Y.

BONNER, JAMES SHEPHERD, Long Line Engineer, Cumberland Tel. & Tel. Co., Nashville, Tenn.

BREMILST, ARTHUR F., Expert Armature Winder, 125 Armory St., Roxbury; res., 63 Lawrence St., Medford, Mass.

BROADWELL, WILLIAM ERNEST, Transmission Engineer, Cumberland Tel. & Tel. Co., Nashville, Tenn.

BURLEEN, OSCAR, Asst. Elec. Engineer, Elevator Supplies Co., Inc., Hoboken; res., 316 Forest St., Arlington, N. J.

BURT, ROBERT C., Research Laboratory, General Electric Co.; res., 22 Gillespie St., Schenectady, N. Y.

CALL, GEORGE RICHARD, Treasurer, Call Bond and Mortgage Co., Sioux City, Iowa.

CASTLEMAN, DAVID JAMES, Greensboro, Ala.

CATLETT, ROBERT LARKIN, Electrician, E. I. du Pont de Nemours & Co., Dye Works, Deepwater; res., Stag Club, Carneys Point, N. J.

*CHESTNUT, ROY W., Waynoka, Oklahoma.

COLLISON, ALFRED B., Traveling Salesman, Southern Electric Co., Baltimore; res., Bayonne Ave., Hamilton, Md.

COOK, FREDERICK ERNEST, Motive Power Office, United Railroads of San Francisco, 1125 Fillimore St., San Francisco, Cal.

COOKINGHAM, EDWARD H., Manager, Telephone & Electric Supply Co.; res., E. 2004, 12th Ave., Spokane, Wash.

*CORDES, HERBERT A., Student University of Southern California; res., 3037 S. Vermont Ave., Los Angeles, Cal.

COTTRELL, LYNN E., General Foreman, Elec. Construction, Submarine Boat Corp., Port Newark; res., 19 Eaton Place, E. Orange, N. J.

COWGILL, MILLER RAYMOND, Supt., Fire Alarm Dept., Victor Talking Machine Co.; res., 108 N. 5th St., Camden, N. J.

CUNERTY, THOMAS JOSEPH, Engineer, Shewan Tomes & Co., 12 Broadway, New York, N. Y.

CUNNINGHAM, FREDERICK JOHN, Asst. Div. Supt., Consumers Power Co., Mechanic & Trail Sts., Jackson, Mich.

DALE, W. JOCELYN E., Electrical Engineer, Compania Azucarera Elia, Ingenio "Elia" Elia., Camaguey; res., Apartado 2593, Havana, Cuba.

DANIEL, WILLIAM ROBERT, Chief Electrician, Radio, Navy Yard, New York; res., Naval Y. M. C. A., Brooklyn, N. Y.

*DEAN, HARRY, Electrician, Bolsover Colliery Co., Mansfield, England.

DE LAPP, CYRIL A., Foreman, Ship Electrical Installation, Federal Shipbuilding Co., Kearny, N. J.; res., 152 Guernsey St., Brooklyn, N. Y.

DEMMERT, WILLIAM CHARLES, Draftsman, American Cyanamid Co., New York, N. Y.; res., 119 Garrison Ave., Jersey City, N. J.

DEVELAZCO, JOSEPH F., Distribution Engineer, Havana Electric Railway Light & Power Co., Havana, Cuba.

DIERKEN, JOSEPH HENRY, Chief Electrician, The Capital Traction Co., 36th & M. Sts., N. W., Washington, D. C.

DOI, KURA, In charge of Engg. Dept., Suzuki & Company, 220 Broadway, New York, N. Y.

DRIVER, EDGAR THOMAS, Elec. Dept., The British Aluminum Co., Ltd., 60 Front St., Toronto, Ont.

DRUMMOND, RALPH S., Asst. Chief Electrician, Morris & Company, Union Stock Yards; res., 7003 S. Green St., Chicago, Ill.

ELLIOTT, FREDERICK FORESTER, Generating Station, London Elec. Supply Co., Ltd.; res., 46 Lansdowne Gardens, London S. W. 8, England.

FEARING, JUSTIN L., Asst. Engineer, U. S. Patent Office, Washington, D. C.

FINK, LOUIS, Electrician, W. & A. Fletcher Co., Hoboken; res., 282 Forest St., Jersey City, N. J.

FLOOD, ARMAND A., Electrician, Eastman Kodak Co.; res., 126 Plymouth Ave. So., Rochester, N. Y.

GIFT, FRANK A., Division Electrician, Plant Dept., Western Union Tel. Co., 515 Bankers Investment Bldg., San Francisco, Cal.

*GILLESPIE, LEIGH R., Telephone Engineer, Stromberg-Carlson Tel. Mfg. Co.; res., 431 Hayward Ave., Rochester, N. Y.

GOLLOS, ANATOL, Electrical Engineer, Chicago Union Station Co.; res., 554 Belmont Ave., Chicago, Ill.

GREEN, JOHN G., General Manager, Kentucky River Power Co., Hazard, Ky.

GROSS, WALTER CLAY, Long Line Engineer, Cumberland Tel. & Tel. Co., Nashville, Tenn.

*GUIMARAES, ARY DE S. M., Engineer, "Prefeitura de Nictheroy", Caixa 545, Rio de Janeiro, Brazil, S. A.

GUTERMAN, HERBERT, Electrical Engineer, University of Paris, Paris, France; res., 53 W. 113th St., New York, N. Y.

HAGEN, CARL, Chief Electrician, Portland Lumber Co.; res., 228 Meade St., Portland, Ore.

HAKANSON, JOEL, Engineering, Export Div., Edison Storage Battery Co.; res., 1935 Daly Ave., New York, N. Y.

HAMILTON, WILLIAM S. H., Railway Equipment Dept., General Electric Co.; res., 11 North Wendell Ave., Schenectady, N. Y.

HARRIES, HARRY GEORGE, Industrial Division, Westinghouse Elec. & Mfg. Co., Chicago, Ill.

*HODGSON, JONATHAN ARCHIBALD, Clerk, C. J. Hodgson & Co.; res., 714 Pine Ave., West, Montreal, Quebec.

*HOPKINS, RALPH A., Sales Engineer, Westinghouse Elec. & Mfg. Co., Los Angeles; res., 681 Oakland Ave., Pasadena, Cal.

HULING, W. H., System Operator, Central Hudson Gas & Electric Co., 67 Montgomery St., Newburgh, N. Y.

HULSE, LEONARD R., 1st Lieutenant Engineers, U. S. Army; res., Army & Navy Club, Newport News, Va.

JOBIM, ADHEMAR DE C., Cia General Electric do Brazil, Caiza do Correiro 109, Rio de Janeiro, Brazil, S. A.

JOHNSON, OLIVER F., Engineer, The Pacific Tel. & Tel. Co., 502 Sheldon Bldg., San Francisco, Cal.

KASAHARA, KENJIRO, Chief Engineer & Manager, Mitsubishi Shipbuilding Co., Ltd., 120 Broadway, New York, N. Y.

KEYS, ALBERT H., Manager, Comanche Light & Power Co., Lawton, Oklahoma.

KIVLIN, JOSEPH F., Appraisal Expert, U. S. A. P. Fabric Inspection Depot, Saylesville, R. I.; res., 55 Peck St., N. Attleboro, Mass.

*KLINEFELTER, LEE M., Electrical Draftsman, Navy Yard; res., 85 Lafayette Blvd., Norfolk, Va.

*KRAMER, ANDREW W., Ensign (E) U. S. N. R. F.; res., 7724 Lowe Ave., Chicago, Ill.

LAING, NORMAN B., Elec. Engineering Staff, Ford Motor Co., 73 Willis Ave. East, Detroit, Mich.

LANKFORD, E. A., Proprietor, Lankford Elec. & Battery Station; res., 605 Story St., Boone, Ia.

LAUBE, OTTO T., Asst. in Research Laboratory, Kellogg Switchboard & Supply Co.; res., 3320 Beach Ave., Chicago, Ill.

LAUER, HENRI, Engineering Dept., Bijur Motor Appliance Co., Hoboken, N. J.; res., 132 W. 85th St., New York, N. Y.

LIPPINCOTT, DONALD K., Chief Engineer, Motor Protector Mfg. Co.; res., 1750 Mission St., San Francisco, Cal.

LIVERMORE, HENRY WELLS, Dist. Manager, Electric Arc Cutting & Welding Co.; res., Hotel Lenox, Boston, Mass.

LOCKE, GEORGE ARTHUR, Electrical Engineer, Western Electric Co., 463 West St., New York, N. Y.

Logan, Henry, Technical Director, L. Sonneborn Sons, Inc.; res., 520 W. 175th St., New York, N. Y.

***Long, Charles Clarke**, 1st Lieut. Engineers; res., 899 Montauk Ave., New London, Conn.

***Ludden, Homer J.**, San Juan, Texas.

Malone, James Edward, Foreman, Interborough Rapid Transit Co., New York; res., 353 57th St., Brooklyn, N. Y.

***Mansfield, Laurence E.**, Automatic Attendant, Western Union Tel. Co.; res., 130 Peoples St., Atlanta, Ga.

Manwaring, Myron, Electrician, Salt Lake County, 427 Vine St., Murray, Utah.

***McAllister, George M.**, Engineering Dept., National Lamp Works of General Electric Co., Nela Park, E. Cleveland, Ohio.

McKechnie, Angus, Asst. Power Apparatus Specialist, Western Electric Co., 84 Marion St., Seattle, Wash.

McMillan, Henry W., Chief Electrician, C. B. & O. Shops, W. Burlington, Iowa.

***Miwa, T.**, Supt., California Vegetable Packing Co. Ltd., 1920 E. Vernon Ave., Los Angeles, Cal.

Nakao, Keiji, Chief Electrical Engineer & Manager of Engg. Dept., Furukawa Mining Co., Yayesucho Kojimachiku, Tokyo, Japan.

Nakasawa, George K., Engineering Dept. Ashio Copper Mines, Ashio, Japan.

Nevatt, Albert E., Inspector, B. & P. Coke Plant, Colorado Fuel & Iron Co.; res., 511 Broadway St., Pueblo, Colo.

O'Brien, Charles M., Supt., Minnesota Electric Light & Power Co., 112 E. Moses St., Cushing, Okla.

***Olson, Victor O.**, 75 New St., Naugatuck, Conn.

Park, Charles D., Asst. Meter Specialist, General Electric Co., 120 Broadway, New York, N. Y.

Pearson, Ernest Helmer, Erecting Engineer, Electric Machinery Co., Minneapolis, Minn.

***Perry, Arlington C.**, Designer, American Rolling Mill Co.; res., 124 S. Harrison Ave., Middletown, Ohio.

Peterson, Charles A., Electrician, Burnside Shops, Illinois Central R. R. 10934 Wabash Ave., Chicago, Ill.

Phelan, George Stanley, Supt. of Elec. Construction, Ideal Coated Paper Co., Brookfield, Mass.

Priddle, William Henry, Draftsman, Toronto Hydro-Electric System; res., 1161 Ossington Ave., Toronto, Ontario.

***Purple, Jay Curtis**, Newark Valley, N. Y.

Pyster, John Neal, Chief Engineer, Raritan Copper Works, Perth Amboy N. J.

Rademacher, William Henry, Engineer in Service Office, Crocker-Wheeler Co., Ampere; res., 216 Weequahic Ave., Newark, N. J.

Rees, John B., Div. Equipment Engineer, Cumberland Tel. & Tel. Co., Nashville, Tenn.

Roe, Fremont Lee, 57th & Grand Ave., Wauwatosa, Wis.

***Roedel, William G.**, Electrical Tester, American Bosch Magneto Corp., Springfield, Mass.

Rogers, Frederick P., Major, Signal Corps. U. S. A., Peoples Bldg., Charleston, S. C.

Ryan, Francis M., Student in Elec. Engg., Univ. of Washington, Seattle, Wash.

Sadler, Ernest K., Dist. Supt., Nevada Valleys Power Co., Battle Mountain, Nevada.

Sauer, Louis B., Chief Inspector, Kellogg Switchboard & Supply Co., Chicago; res., Western Springs, Ill.

Schulz, Paul H., Chief Electrician of Street Lighting, Bureau of Illumination Service, City Hall, Milwaukee, Wis.

Seeley, Charles G., Manager, Melbourne Office, Australian General Electric Co., Queen & Little Collins St., Melbourne, Aus.

Shank, L. D., Manager & Supt., Municipal Light & Water Works, Centerville, Md.

Shapiro, Harry, Draftsman, Goldmark & Harrisson; res., 160 East 84th St., New York, N. Y

Shull, William G., Engineer, Kellogg Switchboard & Supply Co., Aberdeen & Adams Sts., Chicago, Ill.

Small, Vincent E., Electrician, Skinner Eddy Corp.; res., 2622, 45th Ave., S. W., Seattle, Wash.

Sparks, Charles, Asst. Shop Supt., Kellogg Switchboard & Supply Co., Adams & Aberdeen Sts., Chicago, Ill.

Speaker, Charles, Ensign, Navy Dept., Bureau of Steam Engineering, Washington, D. C.

Starkey, Fred Christopher, Chief Electrician, Erie Proving Ground, Port Clinton, Ohio.

Stone, Harris Deming, Electrical Engineer, A. C. Gilbert Co., New Haven, Conn.

Thaxton, Guy Werter, Asst. Engineer of Tests, Elec. Engg. Dept., Tenn. C. I. R. R. Co., Ensley; res., 520, 43rd St., Fairfield, Ala.

Thomason, Joseph J., Asst. Engineer, South Western Gas & Electric Company 1603 W. 8th St., Texarkana, Texas.

Tidd, George W., Prof. of Engineering, Marion Military Institute, Marion, Ala.

Tokarske, John J., Electrician, Colorado Fuel & Iron Co., Minnequa Works; res., 1045 Spruce St., Pueblo, Colo.

Tone, Richard Wolfe, Student, Sheffield Scientific Schools; res., 334 Howard Ave., New Haven, Conn.

Visser, C. Gerald, Testing Dept., General Electric Co., Schenectady, N. Y.

Wayman, P. F., Construction Engineer, Hydro-Electric Power Commission, 190 University Ave., Toronto, Ont.

Weber, William Albert, Sales Dept., Century Electric Co., St. Louis, Mo.

Wells, James Maxwell, Electrical Inspector, City of Riverside, 854 Mulberry St., Riverside, Cal.

Whitaker, Jefferson D., Service Engineer, Westinghouse Elec. & Mfg. Co., 32 So. Peoria St., Chicago, Ill.

White, Charles E., Industrial Engineer, Century Electric Co., 1827 Pine St., St. Louis, Mo.

White, John Walter, Special Representative, Westinghouse Electric Export Co., Havana, Cuba.

Wiederhold, Oscar Charles, Jr., Electrical Mechanic, Thorton Fuller Automobile Co.; res., 4531 Pulaski Ave., Philadelphia, Pa.

Wood, Oliver D., Transformer Engg. Dept., General Electric Co., Pittsfield, Mass.

Wootton, William L., Asst. to Chief Elec. Engineer, New York Edison Co., New York; res., 45 Brevoort Place, Brooklyn, N. Y.

*Former Enrolled Students.

Total 126.

MEMBERS ELECTED AUGUST 12, 1919

Crouse, George B., Dept. Engineer, Sperry Gyroscope Co.; res., 493 Washington Ave., Brooklyn, N. Y.

Fiske, Harold B., Supt., Drummondville Div., So. Canada Power Co., 330 Coristine Bldg., Montreal, Quebec.

Hawley, John Terrill, Supt. of Power House, Sanitary District of Chicago, Lockport, Ill.

Keilholtz, Lester Smeath, Chief Engineer, Domestic Engineering Co., Taylor & Pitt Sts., Dayton, Ohio.

Mullins, R. J., Manager, Northern Iowa Gas and Electric Co., Eagle Grove, Iowa.

Stark, John Roy, Elec. Engineer, Laboratory & Experimental, Webster Electric Co., Racine, Wis.

Thomson, John A., Chief Electrical Engineer, Havana Central Railroad Co., Central Station, Havana, Cuba.

FELLOW ELECTED AUGUST 12, 1919

Ellis, Alvarado Leroy, Asst. Director, Thomson Laboratory, General Electric Co., Lynn; res., 17 Banks Road, Swampscott, Mass.

TRANSFERRED TO GRADE OF MEMBER AUGUST 12, 1919

Alden, Vern E., Asst. to General Superintendent, Consolidated Gas Electric Light & Power Co., Baltimore, Md.

Devereux, Washington, Chief of Electrical Dept., Philadelphia Fire Underwriters Ass'n, Philadelphia, Pa.

Dickinson, Neville S., Electrical Engineer, Elevator Supplies Co., Hoboken; Consulting Electrical Engineer, Nairn Linoleum Co., Kearny, N. J.

Fox, Alfred C., General Superintendent, General Utilities Corp., St. Paul, Minn.

Gaillard, Capt. David St. Pierre, Executive Asst. to Chief of Nitrate Div., Ordnance Dept., U. S. A., Washington, D. C.

Herault, P. C., Supt. Transmission, Georgia Railway & Power Co., Atlanta, Ga.

Hutchinson, Lieut. George E., U. S. N. R. F., New York, N. Y.

Jones, Joseph S., Engineer, Charles Cory & Son, Inc., New York, N. Y.

Joy, William M., Chief of Electrical Design, Electric Bond & Share Co., New York, N. Y.

Kleberg, Alfred L., Captain Q. M. C. Construction Division, Washington, D. C.

Kohlhaas, Herman T., Head of Apparatus Analysis Div., Engg. Dept Western Electric Co., New York, N. Y.

Kribs, Gordon, Assistant Engineer, Hydro-Electric Power Commission of Ontario, Toronto, Ont.

Le Tourneau, Edward H., Electrical Engineer, Portland Railway, Light & Power Co., Portland, Ore.

Lillibridge, Ray D., President, Ray D. Lillibridge, Inc., New York, N. Y.

Lindridge, Charles D., Engineer, Western Electric Co., New York, N. Y.

Maddocks, William S., Head of Electrical Engineering Dept., Lockwood Greene & Co., Boston, Mass.

Mainland, James, Chief Engineer, Washington & Old Dominion Railway, Washington, D. C.

Muir, Roy C., Electrical Engineer, International General Electric Co., Schenectady, N. Y.

Rhodes, Sam R., Associate Professor Mechanical and Electrical Engineering, Clemson College, Clemson College, S. C.

Shoemaker, Richard W., Engineer of Distribution, Great Western Power Co., San Francisco, Cal.

Siegfried, Joseph H., Supt. of Power, Pacific Power & Light Co., Pasco, Wash.

Sorsby, Paul C., Engineering Dept., General Electric Co., Atlanta, Ga.

Turnbull, Thomas L., Consulting Engineer & General Manager, Bowness Improvement Co., Calgary, Alberta.

Vaniman, R. Lawrence, President, Produce Terminal Corp., Chicago, Ill.

Wakeman, Henry R., Supt. of Distribution, Portland Railway, Light & Power Co., Portland, Ore.

Wright, Walter F., Eugene F. Phillips Electrical Works Ltd., Toronto, Ont.

TRANSFERRED TO GRADE OF FELLOW AUGUST 12, 1919

Andrus, Lucius B., Chief Engineer, American Public Utilities Co., Grand Rapids, Mich.

Galusha, Don L., Dwight P Robinson & Co., Inc., New York, N. Y.

Mathey, E. D., Electrical Engineer, Air Nitrates Corp.; Electrical Engineer, American Cyanamid Co., New York, N. Y.

Rosenthal, Leon W., Vice-President, American Bosch Magneto Corp., Springfield, Mass.

Sorensen, Royal W., Professor in Charge, Dept. of Electrical Engineering, Throop College of Technology, Pasadena, Cal.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its regular monthly meeting, held on August 6, 1919, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

Morehead, John M., Consulting Engineer, New York, N. Y.

To Grade of Member

Davis, Archibald, Jr., Senior Lieut., U. S. N. R. F., St. Louis, Mo.

Seeger, Edwin W., Electrical Engineer, Cutler-Hammer Mfg. Co., Milwaukee, Wis.

Thompson, William J., Member of firm, Thompson-Levering Co., Philadelphia, Pa.

Tremaine, A. Raymond, Manager and Chief Engineer, Depew & Lancaster Light, Power & Conduit Co., Lancaster, N. Y.

STUDENTS ENROLLED AUGUST 12, 1919

10440 Robinson, H. E., Clarkson Coll. of Tech.
10441 Kimball, H. R., Worcester Poly. Inst.
10442 Hilderbrandt, P. J., N. Y. Elec. School.
10443 Thompson, I. D., Clarkson School of Tech.
10444 Benscheidt, N. H., Univ. of Kansas.
10445 Anderson, H. C., Sheffield Scientific School.
10446 Langdon, G. G., State Coll. of Washington.
10447 Carlson, C. O., Sheffield Scientific School.
10448 Haugh, H. A., Sheffield Scientific School.
10449 Osgyani, G. L., Sheffield Scientific School.
10450 Schmidt, H., Brooklyn Poly. Inst.
10351 Valldejuby, R. R., J. Y. Elec. School.
10452 Erb, H. G., Penn. State Coll.
10453 Lutsey, S. F., Casino Tech. Night School.
10454 Reid, K. M., Cornell Univ.
10455 Thakkur, K. B., Cornell Univ.
10456 Wise, E. M., Univ. of Wis.
Total 17

PERSONAL

Sidney W. Farnsworth recently returned from his duties as Associate Scientific Attaché at the American Embassy, London. He is now associated with Mark Manufacturing Co., Chicago, as Assistant to the Manager of the Evanston plant.

D. C. Hopper has accepted a position with the Newport News and Hampton Railway, Gas and Electric Company. Previous to the outbreak of the war Mr. Hopper was with the Commonwealth Edison Company of Chicago as Assistant Superintendent of underground cable system and since that time has been in charge of the electric distribution and signal systems of the American International Shipbuilding Corporation.

Dwight P. Robinson and Company, New York, have been awarded a contract by the Duquesne Lighting Company of Pittsburgh, to design and construct a power station at Cheswick, near Pittsburgh, to have an ultimate capacity of 300,000 kw. of which one unit of 60,000 kw. is to be installed initially.

David S. Wegg, Jr. has accepted a position as testing engineer for the Isko Company, Chicago, Ill., manufacturers of electric refrigerating machines. Mr. Wegg has been serving as assistant to the Contracting Officer, Chicago District, Ordnance Dept., U. S. A.

C. J. Berry, for the last six years with the National Lamp Works of the General Electric Company, Cleveland, has accepted a position as electrical engineer with Brandt and Fouilleret, Paris, France. Mr. Berry served as First Lieutenant in the U. S. Air Service in the A. E. F.

ENGINEERING SERVICE BULLETIN

Opportunities.—The Institute, is particularly anxious to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in this BULLETIN. The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Services Available.—Under this heading brief announcements (not more than fifty words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office files.

Note.—Copy for publication in the BULLETIN should reach the Secretary's office not later than the 20th of the month if publication in the following issue is desired.

All replies to either "Opportunities" or "Services Available" announcements should be addressed to the number indicated in each case, and mailed to Institute headquarters.

Engineering Societies Employment Bureau.—This is a joint bureau under the auspices of the Engineering Council. The Institute's employment service is coordinated with that of the joint bureau.

OPPORTUNITIES FOR SERVICE

V-556. Well known electrical firm expanding its export service requires translator to rewrite electro-technical English into technical Spanish chiefly for publications to be distributed in South America. Engineer preferred. Advancement, etc., will depend on ability and expansion of the trade. State qualifications, experience and salary expected.

V-557. A college graduate with some practical or teaching experience is wanted for the position of instructor in the electrical engineering department of a well known college near New York City. Salary $1200 for about nine months' work.

V-558. Assistant to superintendent of power. Technical graduate in mechanical engineering, 1918 or 1919.

V-559. Technical engineers for steam plant betterment work. Men would be required to advise management and coach operating force in economical operation. Tact, willingness to work and combustion experience (oil and gas firing) required. Location southwest. Salary depends on qualifications.

V-560. A graduate of three or four years' standing, age 28 to 30, for general work as assistant engineer in a 100,000 h. p. hydroelectric development. This position offers an early opportunity for advancement to assistant having direct supervision of operation and maintenance followed by responsible charge of development.

V-561. Young man, single, recently graduated from technical school for inspecting and testing electrical apparatus, also general laboratory work. General Electric Company test department experience preferred. Good scholastic record and personality important.

V-562. A trained mechanical engineer with a knowledge of machinery and machine parts. Preference will be given to the man who is particularly qualified from the purely technical side. The use of a good deal of higher mathematics will be necessary in this work. The opportunity offered is that of assistant to the head of the engineering division of a large corporation selling to the machinery field. Salary will be commensurate with demonstrated ability.

Instrument Repairman (Electrical) Wanted for the Panama Canal—$197.60 month. Must be capable of testing, repairing and installing all types of watt-hour meters, and indicating and curve drawing instruments, both alternating and direct current in portable and switchboard types. Also instrument maker, $1.05 hour, thoroughly experienced on engineering instruments. Must be American citizens, final papers, under 50 years of age, in good health. Free steamship transportation from New York or New Orleans, wages beginning date of sailing. Write "Chief of Office, The Panama Canal, Washington, D. C."

The United States Civil Service Commission announces open competitive examinations for the positions of Electrical Engineer (male) $2,400 to $3,600 a year, and Assistant Electrical Engineer (male) $1,800 to $2,400 a year. Vacancies are in the Signal Service at Large, Washington, D. C.

The duties of these positions comprise the development and design of electrical equipment and especially Signal Corps storage batteries, or the administration of commercial telephone systems and installation of Government-owned systems. Competitors will not be required to report for examination at any place, but will be rated on the following subjects; Education, training and experience 60; publications, reports, or thesis (to be filed with application) 40; Applicants should apply for complete particulars and for Form 2118, stating title of the examination desired, to the Civil Service Commission, Washington, D. C.

SERVICES AVAILABLE

1385. Industrial engineer, age 30. Extensive training in electrical and machine design, repair and re-design of motors. Eight years' experience. Now consulting engineer for several rebuilders. Married. Salary $3600.

1386. Executive electrical and mechanical engineer, now administrative officer of large Government plant. Free about Aug. 15. Formerly consulting engineer. Thirty-four years of age, married. Splendid references. Design and construction of steam and hydroelectric plants, special electrical and manufacturing equipment and automatic electrical control systems. Experience in utility work, purchasing and salesmanship. Salary $3000. to $5000.

1387. Power system executive. Engineering graduate; 10 years' experience in construction and operation of high voltage high power generating stations, transmission lines, substations and distribution systems; at present employed at salary above $4500., but desires opportunity for greater service and responsibility in the line of operation, construction or general design.

1388. Young man with excellent record supervising the installation of electrical apparatus and factory equipment desires to connect with plant or company who can use the services of a hustler.

1389. Technical graduate, 27 years of age, with five years practical experience in the manufacture of high voltage insulating materials, including enamel magnet wire, all grades of tape, cloth and paper insulation, fiber plate, rods and tubing. At present employed. Available on short notice. Salary dependent on prospects.

1390. Electrical-Mechanical Engineer desires position with progressive New England manufacturer. Technical graduate, capable of handling the works engineering or acting as assistant to chief engineer of large company. Three years of time study, production, and plant engineering experience. Good personality and executive ability. Interested in permanent position where it will be possible to become financially interested in company. Best references. Single. Age 26. Present salary $170.

1391. Plant Engineer or master mechanic. Technical graduate, excellent executive, successful in handling men of all classes, diplomatic and tactful. Seventeen years experience in electrical and mechanical engineering, including installation and maintenance; power and industrial plant; heating and lighting layout; organization and production engineering; selling and purchasing.

1392. Electrical Engineer, graduate 1918 of middle western university, desires position with good opportunity for advancement. Two months instructor army training detachment, one year Ensign U. S. Navy. Best of references. Age 30. Salary $1900.

1393. Electrical Engineer, graduate 1919, desires position with an electrical contractor or electrical manufacturing concern. Age 22. Eastern location preferred.

1394. Engineer-Salesman. Graduate in electrical and mechanical engineering. Seven years experience with large central station company in new business department. Also several years with electrical manufacturer in sales capacity. Experience in compiling data and reports and in general office routine and methods. Age 33. Available immediately. Salary $2500.

1395. Technical graduate, age 41, married, Associate A. I. E. E. Three years Westinghouse test, motors and generators, year and a half erecting engineer. Seven years superintendent municipal light, power and water works. At present holding such position. Desires change offering responsible position with broader opportunities.

1396. Sales Engineer available at once. Would like to represent some motor or power equipment manufacturer through New England.

1397. Electrical Engineer, technical graduate with over seven years varied experience. One year General Electric test, two and one-half years appraisal, one and one-half years layout of lighting and motor applications, two years purchasing officer electrical apparatus and supplies U. S. Army. Salary $3000.

1398. Mechanical Engineer, age 30, graduate, engineer, specializing in the development, design and construction of electrical and mechanical appliances, devices and instruments requiring inventive ability. Design of automatic machinery for contemplated production. Experienced in factory management.

1399. Graduate Electrical Engineer, age 30, married. Aggressive and ambitious, with executive ability and sales instinct. Eight years experience with utility corporation as tester, construction supervisor, technical correspondent and methods engineer. Desires position with a real future, preferably along consulting or sales engineering lines. Present location New York City.

1400. Electrical Engineer, age 33, university graduate. Ten years diversified experience in engineering, operation and maintenance of hydro and steam power plants up to 100,000 h. p. capacity, d-c. and a-c., low-tension and high-tension, for industrial, mining and power companies. Capable executive. Have successfully managed operating and maintenance forces of 175 men. Available now.

1401. Position wanted by technical school graduate, age 28, with four years experience on estimating and construction of transmission lines; also two years experience on structural steel. Married; prefers location in New England. Would consider being assistant to superintendent of power and lighting plant.

1402. Electrical engineering graduate; General electric test, experienced as construction foreman in power plant construction and operation. Desires position as works electrical engineer or connection with manufacturing company in commercial engineering. Location preferred, Pennsylvania. Associate A. I. E. E. Married, age 24. Salary $2000.

1403. Electrical Engineer, university graduate, age 37. Two years experience telephone line construction and maintenance; ten years experience as executive in charge of railway, a-c. and d-c. distribution systems, including bonding, electrolysis and signals. Desires position as distribution engineer, or would consider proposition from manufacturer of highway-crossing protection.

1404. Available at once. What have you to offer electrical engineer, 30 years of age, and married? Past two years as testing and inspecting engineer motors, generators and mechanical mechanical equipment, six years practical experience in substation and powerhouse construction. Maintenance position desired.

1405. Electrical Engineer, ten years with present employer, starting as electrician, then assistant mechanical engineer, last four years as electrical engineer, desires wider opportunity. Four years, most of time in charge, on test floor, motor and generator manufacturer. Much experience laying out, buying and installing machinery for enlarged factory, College graduate, 37 years old, married. Salary to start $3000-$3600.

1406. Mechanical engineering graduate, one year drafting experience, two years automobile experience, testing oils, gasoline, and gasoline substitutes. Some knowledge of electrical machinery. Desires position in or near New York City. Just returned from service with A. E. F. in France.

1407. Technical graduate, age 26 married, seven years electrical construction experience, Associate A. I. E.E Recently released form U. S. N. R. F. after 18 months engineering duties with Bureau of Steam Engineering, U. S. N. Desires position with lighting and power company, preferred. Will accept $1800 to start with opportunity for advancement.

1408. Lieutenant, U. S. Army, just returned from A. E. F. desires position with power or construction company. Graduate electrical engineer, single, age 28. Four years operation and maintenance engineering with central station organization. Three months valuation work. Enlisted U. S. Army June 1917. Best references from all employers. Salary $2000.

1409. Graduate Electrical Engineer, Associate A. I. E. E., age 29, married, desires position. Specialist in design, maintenance and construction of overhead and underground transmission and distribution lines. Experienced in inside wiring, sub- and central stations. In executive capacity last five years. At present in Army, but expect discharge in 30 days. Salary $3000.

1410. Public Utility expert in service of two important Public Utility Commisssions for past ten years and fully qualified to handle valuation and rate cases involving electric, water, gas telephone, sewer and railway utilities, is available for consulting work or will consider permanent connection with suitable organization. A1 record and references.

1411. Electrical Engineer, technical graduate, five years experience with a hydro-electric power and transmission company, including tests, drafting, station and system operation and general operating engineering, desires an engineering position with an engineering or operating company.

1412. Electrician desires an opportunity which may lead to executive position. Four years experience power house construction, General Electric and Westinghouse test floor practise, and mill maintenance. Associate, A. I. E. E.

1413. Graduate electrical and mechanical engineer, age 39, American, married. Total of nineteen years experience, principally design, construction and operation of electric railways, steam and hydro-electric power plants, substations and transmission lines. Do not like present work. Minimum salary $3600.

1414. Physicist, chemist and author of work on electrical measurements. Reputation well-known for scientific discoveries. Twenty years experience in physical laboratory teaching and lecturing at one of the great universities. Desires position either in commercial research work, or teaching physics or chemistry.

ENGINEERING SOCIETIES LIBRARY

The library, which comprises the individual libraries of the American Institute of Electrical Engineers, the American Society of Mechanical Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Civil Engineers, and the United Engineering Society, is located on the thirteenth and fourteenth floors of the Engineering Societies Building. In addition to engineering works it contains general reference books on allied sciences such as Physics, Mathematics and Chemistry. The library also contains publications of practically all the engineering societies in the world as well as current and bound sets of more than 1,000 engineering periodicals in English and other languages.

In order to place the facilities of this great engineering library at the disposal of persons residing out of town, a Library Service Bureau has been established, and a staff of expert searchers and translators is prepared to cover almost any engineering topic. Charges for service are at actual cost. Ph tostat copies of prints, drawings, etc., are $0.25 per 10 x 14 inch sheet.

All communications should be made as definite as possible so that the information received may be what is desired and not include collateral matter of no interest. The time spent in searching for such collateral matter will be saved, and information sent more promptly and in more usable shape.

Members who may desire it will be kept informed regarding current publications on any engineering subject for a small annual fee.

The library is conducted as a free public library of reference. It is open to the public from 9 a m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a.m. to 6 p.m.

Book Notices.—(July 1-July 31, 1919) Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

ABRASIVES AND ABRASIVE WHEELS:

Their Nature, Manufacture and Use. A complete treatise on the manufacture and practical use of abrasives, abrasive wheels and grinding operations. By Fred B. Jacobs. N. Y., The Norman W. Henley Publishing Co., 1919. 338 pp., 174 illus., 1 por., 8 x 5 in., cloth, $3.

This work opens with descriptions of the various natural and artificial abrasives, the manufacture of grinding wheels and artificial sharpening stones, the grades established in commerce and the methods of testing grinding wheels. Chapters follow on the care of wheels, dust collecting systems and safeguards, abrasive papers and cloths, methods of surface, cylindrical an internal grinding, special grinding operations, and cutter and saw sharpening. The author writes from experience as a machinist and as a salesman of grinding wheels.

AIRPLANE DESIGN AND CONSTRUCTION:

By Ottorino Pomilio. 1st edition. N. Y., McGraw-Hill Book Company, Inc.; Lond., Hill Publishing Company, Ltd. 1919. 403 pp., 248 illus., 58 tab., 9 x 6 in., cloth, $5.

A book on the structure and design of airplanes, in which the results of European experimental research in aerodynamics are presented in considerable detail. The problems relating to airplane design and operation are analyzed, working formulas are derived and the data needed by designers are presented.

THE APPLICATIONS OF ELECTROLYSIS IN CHEMICAL INDUSTRY:

By Arthur J. Hale., Lond. and N. Y., Longmans, Green and Co., 1918. 148 pp., 56 illus., 9 x 6 in., cloth, $2.50. (Monographs on Industrial Chemistry).

The author describes briefly the electrolytic refining and winning of metals; the production of hydrogen and oxygen, chlorin, caustic soda, hypochlorites, chlorates and perchlorates; and of various other organic and inorganic compounds. References to the literature and patents are included.

A CENTURY OF SCIENCE IN AMERICA:

With special reference to the *American Journal of Science*. 1818-1918. By Edward Salisbury Dana and others.

New Haven, Yale University Press, 1918. 458 pp., 22 por., 9 x 6 in., cloth, $4.

The present book commemorates the one-hundredth anniversary of the founding of the *American Journal of Science* by Benjamin Silliman in July, 1818. The opening chapter gives a somewhat detailed account of the early days of the *Journal*, with a sketch of its subsequent history. The remaining chapters are devoted to the principal branches of science which have been prominent in the pages of the *Journal*; geology, paleontology, mineralogy, chemistry, physics, zoology and botany. They have been written with a view to showing in each case the position of the science in 1818 and the general progress made during the century. Special prominence is given to American science and particularly to the contributions to it to be found in the *Journal's* pages.

ELECTRICAL AIDS TO GREATER PRODUCTION:

Plans, methods and appliances by which industrial electrical engineers are meeting increased demands for power. Compiled and edited by Allen M. Perry. 1st edition, N. Y., published by *Electrical World*, McGraw-Hill Book Company, Inc. 1919. 332 pp., illus., chart, tab., 9 x 6 in., cloth $2.

CONTENTS: General Power Problems of Industrial Plants; Distribution, Transformation, Switching, and Protection; Motors, Control, Specific Applications, Troubles and Remedies; Illumination—Selection of Equipment, Economies, and Specific Applications; Electric Furnaces, Welding, etc.; Meters and Measurements as Applied to Industries; Handling Material in Industrial Plants with Electric Tractors; Outdoor Substations.

The engineering editor of the *Electrical World* has prepared this volume from the articles on the application of electricity to plants which have appeared in that periodical during the last few years. It summarizes the methods that have arisen from the necessity for increased factory output and reduced cost of production caused by the war in many classes of industries.

INDUCTION COILS IN THEORY AND PRACTICE:

By F. E. Austin. [Hanover, N. H., copyright 1919] 64 pp., 45 illus., 9 x 6 in. cloth, $1.

A presentation of the fundamental principles of the induction coil, for use as a text-book. Intended to enable the student to construct induction coils to meet a variety of demands as well as to construct coils to fulfill specific requirements.

AN INTRODUCTION TO THE PHYSICS AND CHEMISTRY OF COLLOIDS:

By Emil Hatschek. Third edition. Phila., P. Blakiston's Son and Co., 1919. 116 pp., 17 illus., 7 x 5 in., cloth, $1.50.

This small volume is intended to introduce readers with a reasonable knowledge of physics and chemistry to the fundamental facts and methods of this important branch of physical chemistry.

Small additions and corrections have been made to this edition, to include such recent advances as fall within the scope of a brief introductory work.

LABORATORY EXPERIMENTS WITH DIRECT CURRENTS:

By F. E. Austin. [Hanover, N. H., copyright 1917] 152 pp., illus., 7 x 5 in., flexible cloth. (Gift of author).

A laboratory course, covering about forty hours, for students in technical and industrial high schools, etc., based on the author's experience as a teacher. The chief aim is to make evident some of the engineering applications of direct currents.

MACRAE'S BLUE BOOK:

Chic. and N. Y., MacRae's Blue Book Co., 1919. 1846 pp., 12 x 9 in. cloth, $10.

This record of manufacturers is intended for use by purchasing agents interested in iron and steel products, building materials, railway supplies, etc. It includes an alphabetical address list of the principal manufacturers in the United States, a classified index of the makers of 10,000 products, an index of trade names, a collection of miscellaneous data useful to purchasers and users of the articles considered, and the standard list prices of building materials, iron and steel products, etc.

MINERAL DEPOSITS:

By Waldemar Lindgren. 2nd edition. N. Y., McGraw-Hill Book Company, Lond., Hill Publishing Co., Ltd., 1919. 957 pp., illus., tab., 9 x 6 in., cloth, $5.

Mineral deposits are usually classified and described by the metals or substances which they contain; for instance, deposits of copper are described together, with little or no effort to separate them into genetic groups. This book is the outcome of a desire to place the knowledge of mineral deposits on the broader and more comprehensive basis of a consistent genetic classification and thus bring it into a more worthy position as an important branch of geology.

In this second edition, all of the chapters have been revised and several have been largely rewritten. A discussion of metallogenetic epochs has been added, as well as an index by elements. Some less essential descriptions have been excised, in order that the book might not increase in bulk.

PRACTICAL HELPS for the Electric Railway Shop, Track, Power, Line and Rolling Stock Departments.

Compiled from *The Mechanical and Engineering Edition of Electric Railway Journal.* 1st edition. N. Y., published by Electric Railway Journal, McGraw-Hill Book Company, Inc., 1919. 331 pp., illus., tab., 9 x 6 in., cloth, $2.

CONTENTS: Track and Structures, by R. C. Cram—Power Generation by Hartley LeH. Smith.—Power Transmission, by Charles R. Harte.—Car Design, by Norman Litchfield.—Car Equipment, by C. W. Squier.

These extended articles have been selected from a series published in the *Electric Railway Journal,* which was prepared for the information of men responsible for the upkeep of the physical equipment of an electric railway system. The articles cover the fundamentals of the various subjects in a broad, practical manner.

STANDARDIZATION OF MINING METHODS:

By Charles A. Mitke. A series of important articles reprinted from *Engineering and Mining Journal.* 1st edition. N. Y., published by *Engineering and Mining Journal,* McGraw-Hill Book Co., Inc. 1919. 110 pp., 47 illus., 6 charts, 4 tab., 7 x 5 in., cloth, $1.50.

As mining engineer for the Phelps Dodge Corporation, the author has studied mining practices in detail, with a view to the establishment of standard methods. The present volume is based on his experience and is an account of the standardization of various mining practices in the interests of safety and economy.

A SYSTEM OF PHYSICAL CHEMISTRY:

By William C. McC. Lewis. 2nd edition. 3 vols. N. Y. and Lond., Longmans, Green and Co., 1918. diagrams, 9 x 6 in., cloth, $4.50.

Professor Lewis' work is intended as a general textbook for use by those who already possess some knowledge of both physics and chemistry and as a fairly comprehensive account of our present knowledge. It is well equipped with references to the original literature, and so is useful for reference use.

The third volume, on the Quantum theory, has been added in this edition. Other changes, necessitated by the advances made since the previous edition, have caused considerable expansion of the book.

TIMBER:

Its Strength, Seasoning, and Grading. By Harold W. Betts. 1st edition. N. Y., McGraw-Hill Book Company, Inc.; Lond., Hill Publishing Company. 1919. 234 pp., illus., maps, charts, tab., 9 x 6 in., cloth, $3.

This volume, for engineers, manufacturers and users of lumber and wood material, is intended to meet the lack of a work on wood as a structural material, similar to existing handbooks on steel, concrete, etc. The methods of testing the strength of wood and wood products, such as telephone poles, packing boxes and vehicle parts, are described and the results of numerous tests by the Forest Service are tabulated. A table based on 130,000 tests, showing the average mechanical properties of 124 American woods, is given. Proper methods of seasoning wood are fully discussed. The grading rules of the different manufacturers' associations are given and the book closes with extensive statistics on the lumber produced and used in the United States.

DEVELOPMENT OF THE INSTITUTE

LETTER FROM THE PRESIDENT

August 19, 1919.

TO THE MEMBERSHIP OF THE
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

In connection with the forthcoming year's activities and with particular reference to the recommendations of the Committee on Development, it is essential that a careful study be made of our finances and while, in advance of such a study, no accurate figures are available, some approximations must be before us, otherwise intelligent consideration cannot be given to the questions on which the opinions of all members have been invited. Therefore, I hope you will consider that I am justified in laying before you the following information.

A reference to the last annual report shows that our revenue for the year ending April 30, 1919 was $134,944.32 and that practically this entire sum was needed to defray current expenditures. The Institute, like every other organization, has now to face the increased and still increasing costs of operation and it is therefore certain that, even if we are to continue our activities unchanged, a larger expenditure will be required in the future than has been necessary in the past. It has in fact come to my knowledge that at least two other National Engineering Societies are seriously considering an increase in their dues in order to provide for this increased expenditure.

Communications to the Development Committee have clearly demonstrated that there is a strong general sentiment throughout the membership in favor of progress and expansion in order that the Institute may keep up with the times and be alive to its possibilities, so that it can retain the prestige which its past record has secured and can remain, as we all want it to, one of the leading engineering organizations of the Nation. Nothing is more certain than that increased activity means increased expenses and it must therefore soon be decided how far our activities are to be limited by our pocketbook and what if any means shall be adopted to increase our income.

Cooperation of the Institute with the other National Engineering Societies, and with local bodies, as a means of increasing the usefulness of the engineer in public affairs and his advancement as an individual has been almost universally demanded, not only by our own membership, but by the membership of the other three National Societies as well; but such an effort will not only be barren of results but will in fact bring ridicule and contempt upon the profession by failure if it shall not be backed with the necessary sinews of war. The amount of money required for this activity will of course be determined by its extent and no present figure can be better than a guess, however judging by a two years experience on Engineering Council hampered from the beginning by lack of funds yet called upon to occupy an ever widening field, $15,000.00 per year would be a modest estimate of the Institute's share of this expense.

Another almost universal desire of our membership is that the central organization and the sections should be brought into closer contact. As a means of accomplishing this purpose, your Development Committee has suggested the holding of Institute and Board meetings more generally in different parts of the country, also that Geographical Divisions be created with a Vice President from each whose duty in addition to attending Board meetings shall include a tour of his Division at least once a year. The American Society of Civil Engineers, with a total membership only a little smaller than ours, has created thirteen such divisions. If it shall be found that the same number will suit our requirements, we will have thirteen instead of six Vice Presidents and therefore seven additional Board members. In order to help insure the attendance of Board members at board meetings, your Development Committee has recommended that their travelling expenses be paid, as is now done by both the American Society of Civil Engineers and the American Society of Mechanical Engineers, which recommendation along with that for the payment of the Vice President's expenses when visiting the sections in their respective divisions would probably require an annual outlay of approximately $18,000.

Suggestions from the membership as to changes in our publications are many and varied but practically all of them favor the printing of some kind of additional matter and of course, every extra printed page means extra expense. The extent of such expenditure obviously cannot be determined until some definite plan has been proposed but for the purpose of having some figure before us suppose we estimate that the increased cost of the publication will be $25,000 per annum.

The additional cost of running the Institute without change is not easy to predict but a 10% increase would certainly not be regarded as abnormal, *i. e.*, $12,500.00.

Summarizing the foregoing figures, we therefore have

Cooperation with other Engineering Societies	$15,000.00
Travelling expense of Board members	18,000.00
Increased cost of publications	25,000.00
Increased cost of operation	13,500.00
Total	$71,500.00

or an increase of over $7.00 per member for a membership of 10,000.

The foregoing figures are confessedly approximate and inserted for the purpose of illustration only, but it is fairly safe to say that the increased annual costs will in no case be less than $5.00 nor more than $10.00 per member and therefore the question at once arises, where is the money to come from?

Shall we increase our dues? Shall we seek to obtain additional revenue from some other source or shall we forego some or all of our proposed new activities? Even if we do not expand we shall still be confronted with the increased high cost of living so that even a stand pat policy is impracticable. We must either provide additional revenue or curtail.

Members of the Society of Mechanical Engineers have solved a similar problem for themselves by expanding their monthly publication into a journal, using the so-called standard periodical page—9 in. x 12 in.—and by securing a substantial increase in their advertising clientele. As a result their financial problems, at least for the time being, are behind them, no increase in dues is thought of and they are not only willing but able to give to their membership every one of the advantages which we so dearly covet but which as yet we cannot afford. I am informed that when the expansion was first suggested, it was vigorously opposed by a large number of members of the

American Society of Mechanical Engineers but that the question now receiving consideration is whether or not the publication shall be made into a weekly instead of a monthly. There seems to be no thought of going back to the old order.

"What man has done, man may do" and this experience of our sister society furnishes us with an interesting object lesson. Your Development Committee felt that an aggressive advertising policy conducted along the proper lines and on a high plane was in no sense inconsistent with the maintenance of our past and present high standards of which we are at the same time both so jealous and so proud. No essential difference could be detected between the ethics of our present advertising policy now sanctioned by long practise and yielding last year about $8,000.00 gross, and a more intensive application of the same policy which might be expected ultimately to yield several times that figure. As contrasted with the unpalatable alternative of adding, possibly $7.00, to our annual dues, the Committee was of opinion that the membership would have strong preference for increased advertising and it framed its report accordingly.

It should be of course, clear that an advertising policy and an editorial policy are two distinct matters and must not be confused. We may or may not like the Journal of the Mechanical Engineers. We may favor any one of the many suggestions offered for the improvement of our own Proceedings. Such questions should be decided on their own merits and not confused with the ethics of advertising. The only ways in which our advertising policy will affect our editorial policy is that on the one hand, if we expect to receive advertising support we must issue a publication which will be read, and on the other hand if we do not get increased advertising revenue we shall have no money to pay for any sort of publication expansion.

Such economies as have been proposed in printing and distributing papers and in avoiding duplicate expense in issuing the Transactions, even if they could be all fully realized, would still fall far short of securing the revenue which now seems essential.

In accordance with the resolution of the Board of Directors at its August meeting, the publication question and all communications from every source relative thereto have been referred to a Special Publications Committee which is already at work. If any change is to be made in our practise there is an obvious advantage in making it effective January 1st, 1920. The next board meeting is scheduled for October, at which time a decision should be made; therefore in order that the Publication Committee may fully consider all suggestions from the membership, it is desirable that same should be at hand at the earliest possible date. Every one who is interested is earnestly urged to give these matters as much study as he believes them to merit and to send his comments thereon to the Secretary as promptly as possible. If you do not express your views either in support of, or in opposition to the Development Committee's report, neither the Publication Committee nor the Board will know about them, and you may not like the action—or lack of it—which may result.

CALVERT TOWNLEY,
President.

RESOLUTIONS ADOPTED BY THE BOARD OF DIRECTORS, AUGUST 12, 1919

RESOLVED, that the report of the Committee on Development be received, with an expression of hearty appreciation of the valuable services rendered to the Institute by the Committee.

RESOLVED, that the recommendations in the report of the Committee on Development, dated August 12, 1919, be hereby approved in principle and that the President refer the various parts of the report to qualified committees, either existing or special, the President being hereby authorized to appoint such special committees as he deems desirable, with the request that these committees formulate definite plans of procedure with estimates of expense involved, for bringing into effect such changes in present practise as the committees deem desirable; also that these committees give careful consideration to such additional communications as may be received from the membership relating to subjects with which the committees are dealing. These reports to be presented at the October meeting of the Board.

RESOLVED, that the report of the Committee on Development, dated August 12, 1919, be released for publication, with particular reference to the technical press; and that it be published in full in the next issue of the Institute PROCEEDINGS, with a request to the membership that the report be carefully considered and that comments upon it or additional suggestions relating to Institute activities be forwarded promptly to the Secretary of the Institute, so that they may be received by him prior to October 1 and be promptly referred for consideration to the various committees and officers concerned with the particular activities to which the communications may relate.

RESOLVED further, that the Committee on Development be continued, with particular reference to the consideration of the Institute's participation in joint activities with various other engineering and technical organizations, which activities are now under consideration by the Joint Conference Committee of the development committees of several national engineering societies.

NOTE: In accordance with the above resolutions, President Townley has referred the various parts of the Development Committee's report to the Institute committees on Publications, Meetings and Papers, Technical Activities, Sections, Student Branches, Law, and Development. The portion of the report relating to engineering education was referred to Engineering Council.

The membership of the Institute is urged to give careful consideration to the various recommendations embodied in the report, and to communicate their views promptly for consideration by the various committees.

F. L. HUTCHINSON
Secretary

REPORT OF COMMITTEE ON DEVELOPMENT

To the Board of Directors,
American Institute of Electrical Engineers.

Gentlemen:

The Committee on Development begs herewith to submit its report.

This Committee was appointed by the President pursuant to a resolution of the Board passed at the meeting of October 11, 1918, and reading as follows:

> **RESOLVED;** that a Committee on Development be appointed by the President to consider suggested or proposed modifications, in the field and methods of work of the Institute, and to make recommendations to the Board of Directors concerning these matters.

We are informed that each Section was invited to nominate its representative of the Committee and owing to the delay of some Sections in responding to this invitation, several months elapsed before the President was able to appoint the Committee.

Subsequently at a meeting of January 10th, 1919, a further resolution was passed by the Board authorizing the appointment of an Executive Committee, *viz.*:

> **RESOLVED;** that the President be authorized to appoint an Executive Committee from the membership of the Committee on Development, for the purpose of considering the various suggestions that may be submitted and outlining a working program for the main committee.

In a letter dated January 27th the President explained what was sought to be accomplished by the creation of the Committee on Development and outlined a suggested course of procedure, following which on February 4th, the Executive Committee held a meeting in New York and prepared a communication to the Section members of the Committee, dividing the subject to be considered into three major headings, namely:

1. The Relation of the Institute to its members.

2. The Relation of the Institute to other engineering organizations.

3. The Relation of the Institute to the public.

Under each heading a series of questions was set up designed to bring out as full a discussion as possible and to make it clear that it was the duty and privilege of the Committee to consider every angle of Institute affairs. This letter in addition to being sent to each member of the Committee on Development was published in the March PROCEEDINGS along with the President's letter of January 27th and accompanied as well by an invitation addressed to the membership at large, whether or not connected with a Section, to send in suggestions.

Attention was again called to the matter in a printed notice, mailed to the entire membership under date of March 20, in which the membership was urged to submit suggestions promptly through any member of the committee.

A subsequent reminder was addressed to the Section members of the Development Committee announcing that a meeting of the Executive Committee would be held on May 8, 1919, at which time communications had been received from 16 sections and from a number of individual members. Most of these communications showed clearly that the Sections had given the matter earnest and careful study, had realized the opportunity that was being offered them and were anxious each to do its part. It was gratifying to the Executive Committee to find that there was such a general unanimity of opinion on many of the questions considered as to indicate very clearly the wishes of the great body of the members and incidentally to make the work of the Executive Committee in compiling the views of the different Sections remarkably simple.

A summary of the views presented was prepared and a tentative plan of procedure outlined by the Executive Committee and sent to the Section members of the Committee on May 13th with the request for their further comment and criticism. Responses to this communication were received from the following: Sections: Detroit-Ann Arbor, Erie, Fort Wayne, Indianapolis, Milwaukee, Pittsfield, St. Louis, and Toronto; Individuals: L. C. Marburg, C. L. Clarke, C. Francis Harding, P. M. Lincoln, and Harold S. Osborne.

The tentative plan of procedure was very generally endorsed either entirely or with minor modifications. The Executive

Committee believes that the reasons that more Sections did not respond to a criticism of the tentative plan was that many of them found the plan satisfactory and thought it would go through automatically if they did not object.

A third meeting of the Executive Committee was held on June 16th and a report to be presented to a meeting of the full Committee at the Annual Convention was prepared, the same being the original tentative plan as modified to meet the criticisms received.

At the Lake Placid Convention the Section delegates voted to merge their meeting with that of the Development Committee, and a meeting of the Development Committee and Section delegates was accordingly held on June 25th, beginning at 1.00 P. M. at luncheon and continuing until after 6.00 o'clock. The President, the Board of Directors, several Past-Presidents and a few guests accepted the Committee's invitation to sit with them and the entire report was very fully discussed. On the following morning the Chairman presented the recommendations of the Development Committee to an open session of the Convention which adjourned until the evening of the same day and discussed the report at length. The recommendations which follow are the result of the foregoing proceedings. It was felt that unless the consensus of opinion among the membership at large be obtained a satisfactory plan would not be forthcoming. Your Committee believes that such consensus of opinion has been obtained and recites the activities of the Committee as its basis for that conclusion. There are also attached hereto, for convenient reference, the following exhibits:

I. Circular letter, dated February 18, 1919, addressed to members of the Development Committee by the Chairman and including the President's letter, dated January 27th, also list of Committee members.
II. Original responses from the Sections and from individual members.
III. The Executive Committee's report to the Development Committee, dated May 13th.
IV. Original comments on the reports of May 13, from Sections and individual members.
V. The Executive Committee report of June 20th as submitted to the Development Committee, Section Delegates, Board of Directors and Past-Presidents at the Annual Convention, June 24th.
VI. Tentative draft of constitution for local affiliation prepared by Messrs. Hall and Robinson as a subcommittee and read to the Development Committee on June 24th.

VII. Stenographic report of the Convention sessions of the Development Committee and of the Institute.

VIII. The reports of the corresponding committee of the A. S. C. E., A. S. M. E. and A. I. M. & M. E. submitted to their respective Boards.

IX. Original communications received since the Annual Convention with reference to the work of the Committee.

There is an almost unanimous view that the PROCEEDINGS do not seem sufficiently to interest the membership at large, and the suggestions of a remedy cover a wide range of possibilities. The value of the class of papers which heretofore have been published in the PROCEEDINGS as representing advances in the art and constitute a record of progress is appreciated and it is insisted that the high standard of the Institute should be maintained but it is believed that this view is not inconsistent with a recognition of the rights of 90 per cent or perhaps 95 per cent of the total membership who are concerned with the day to day engineering problems and with the personal side of engineering relationships. It is believed that if the PROCEEDINGS can be properly expanded that publication will serve better to both bind the present membership closer together and furnish an added incentive for engineers not already members to join. The Development Committee has devoted a great deal of time to discussions of this matter but feels that with the recommendations of the various Sections and the stenographic report of the Lake Placid meetings to be considered, further study should be given to this matter in order that the very best plan may be adopted. The Committee therefore, submits the following recommendations, to wit:

Publications

That the Publication Committee be asked to consider and recommend to the Board improvements in the present plan of publishing the PROCEEDINGS and the TRANSACTIONS and of printing and distributing copies of Institute, Section and Branch papers.

That in dealing with these questions the Publication Committee consider:

(a) Enlarging the editorial and executive publication staff for the purpose of expanding the PROCEEDINGS to contain additional live matter of interest and value to the membership as a whole without giving less importance to the principal activities of the Institute, *i. e.*, the promotion of the fundamental advance in the art and the encouragement of original investigation in the field of electricity.

(b) Publishing all Institute papers and occasional papers of unusual broad general interest and value from Sections or from other sources; publishing a set of abstracts of every paper presented to every Section so that each month there will be a complete record of this class of Institute activity.

(c) Eliminating as far as may be feasible the duplication of expense now incurred by twice publishing the papers heretofore distributed (in both the PROCEEDINGS and the TRANSACTIONS) but without depriving the membership of the TRANSACTIONS in some form.

(d) Publishing discussions in the PROCEEDINGS.

(e) Endeavoring to increase the revenue producing capacity of the PROCEEDINGS by expanding its advertising policy and if necessary changing its page dimensions.

(f) Printing pamphlet copies of some or all Section, and perhaps Branch, papers and economizing on the cost of printing Institute and such Section and Branch papers by limiting their quantity and free distribution while making them available for the membership.

Note.

In considering the foregoing summarized recommendations the Publication Committee is asked to examine the stenographic report of the Lake Placid sessions of the Development Committee and of the Institute hereto attached.

Another unanimous desire of the membership is for closer contact between the Institute officers, prominent engineers and Sections as a means of improving the morale of our organization, stimulating Section activities and of interesting the membership at large, particularly the younger members in Institute work. With the large number of Sections and Branches now in existence and the probability that this number will increase it seems obvious that if the present Institute officers were to comply with this demand they would have time for nothing else and even then the demand would not be satisfied. An obvious alternative therefor is to have more officers and let them be chosen from different parts of the country. If this be done and these officers are to be really participants in the Institute management and not simply visiting functionaries, means must be provided to insure their attendance at Institute and Board meetings. It is believed that these objects can be accomplished by decreasing the number of Institute meetings, thereby reducing the demand of the time of its officers by holding them in different parts of the country thus making it easier for those residing at points remote from headquarters to attend and by paying the expenses of Board members when in attendance. If the Institute meetings be not held in New York it almost naturally follows that the New York members constituting a very large and important per cent should organize a Section so that their present opportunities may be expanded instead of abridged.

In order to accomplish the results described, the Committee makes the following recommendations, namely:

Organization.

(a) That a New York Section be organized and conducted on the same lines as existing Sections elsewhere.

(b) That the present practise of holding some of the Institute and Directors' meetings in different localities, where local Sections are established, be extended, instead of holding nearly all of these meetings in New York as at present. It may be desirable to reduce the frequency of Institute and Directors' meetings and hold them every two months or perhaps even less frequently instead of every month as now.

(c) That the country be divided into geographical divisions corresponding in number to the number of Institute Vice-Presidents. If more than six divisions should be thought desirable, they should be established and the number of Vice-Presidents increased to correspond. In order to allow for the future shifting of membership density and at the same time to escape the necessity of cumbersome constitutional amendments the number and delimination of geographical divisions should be specified in the by-laws instead of the constitution to provide for ready amendment by the Board of Directors.

(d) That one Vice-President be selected from each geographical division, the President and Managers to be elected from the membership at large as at present.

(e) That the Institute should pay the traveling and living expenses of the officers and Board members when attending Institute meetings.

(f) That it be the duty of each Vice-President to visit each Section in his own division at least once a year, the Institute to pay his traveling and living expenses for such visits. Of course it would also be desirable if the Vice-Presidents could exchange visits.

(g) That the Vice-Presidents' term of office be lengthened from one year to two years and the constitutional inhibition against the election of a Vice-President as Manager be removed. Provide against too extended tenure of office by a constitutional provision that except in the case of a Manager or a Vice-President, who may be elected President, no member may continuously hold office longer than six years.

Activities.

(a) That committee work be decentralized as far as it may be found feasible and desirable by substituting Section committees for Institute committees. Appoint a general committee to study this question and make recommendations.

(b) That more high grade papers of general engineering interest be presented.

(c) That a committee be created in each Section charged with the duty of assigning to the younger members specific participation in designated meetings by the preparation of papers, discussion or otherwise. It is hoped by this means and by the appointment of a reasonable number of the younger men to the larger committee membership caused by decentralization, that the interest of the younger men will be stimulated, and their loyalty increased.

There is a universal recognition of the fact that engineers do not participate as actively or as prominently in public affairs as they should and that both the public welfare and their own individual advancement would be promoted if this condition could be rectified. There are two general reasons believed to be responsible for the existing condition, one a lack of any general organization of engineers which would facilitate their cooperation, and second, too great technical specialization in the engineering curricula of our technical schools and colleges which tend to narrow the vision of the engineering student and start him on his career with an exaggerated idea of the importance of specialization and an insufficient appreciation of the part he must play in public affairs.

The first of these reasons was very generally brought up in one form or another by the Sections and although it is recognized that a corrective can be applied by our Institute only in cooperation with other engineering bodies, it was felt that we could properly take a constructive step by adopting a skeleton plan for cooperation and then appoint conferees who could discuss the matter with similar conferees from other societies and endeavor to agree to definite recommendations to their respective governing bodies. With this object in mind the Committee respectfully recommends:

Local Federations.

(a) That a comprehensive but flexible uniform outline for the federation of local engineering bodies be prepared taking advantage of the experience already gained by existing affiliations.

(b) That we use our endeavors to have the other national societies establish and support local Sections along lines similar to ours but do not confine local federations to such branches, rather planning to include all the worthy engineering bodies.

(c) That wherever such federations can be organized there be established under an appropriate name a federated local council of engineers to be made up of a properly apportioned number of representatives from the different locals.

National Council.

(a) That there be established a direct touch between each local federated council and a National Engineering Council composed of delegates from as many National engineering societies as are willing and worthy to participate.

(b) That through the medium of the National and the local federated councils there be perfected a working arrangement for engineering cooperation in all public affairs where such is desirable.

Engineering Congress.

That there be inaugurated the custom of periodically holding an Engineering Congress, the delegates to which should be selected from all parts of the country under a plan to be developed for suitable representation, this Congress to consider and take action on such matters of general interest to engineers and to the public as may merit its attention and as have been previously advertised, for a sufficient length of time, to permit locals everywhere to give them consideration and when possible to send instructed delegates.

Engineering Curricula.

The second reason, namely, a possible modification of the engineering curricula of our technical schools and colleges while perhaps of underlying and fundamental importance not only did not have the general consideration of many of the Sections in their local deliberations but was nearly crowded off the Lake Placid program by the press of other matters. It was, however, the unanimous view of the members attending the sessions at Lake Placid that this matter should receive early and thorough consideration by the Institute, and the following preamble and resolution was there presented and adopted:

> As the individual engineer cannot look for greater public recognition or individual advancement than his training and fitness warrant.
>
> And, in the belief that the bigger development of the profession consists in broader social and public service by publicly-minded engineers,
>
> Recognizing that on the one hand young engineers are employed for too long a period at work which does not stress their capabilities and, on the other, that the demands of industry for ever-increasing numbers of technicians must be supplied,
>
> And having in mind the excellent precedents established by the medical and legal professions,
>
> This Committee would welcome the establishment at the earliest date practicable of a normal six years' collegiate course in engineering, two years of which at the least should be devoted to training in the humane arts and sciences including, for example, Political Science, Economics, History and General Letters; the last four years being devoted to sound training in the sciences and in only the fundamentals of diversified engineering.
>
> With or prior to such a development we would endorse a program for the marked extension of vocational training in the industrial centers in order that the needs of industry may be met.
>
> To the accomplishment of these ends this Committee requests the appointment of representatives to serve on a Joint Committee of Engineering Organizations to promote such a national educational program as shall provide for the future necessities of the engineering profession consistent with the needs of society.

Student Branches.

Closely allied to the consideration of curricula is our policy toward the student branches, and the Chairman of the Institute

Committee on Branches attended the Lake Placid session and was good enough to bring this question forcibly to the attention of the Committee. Whereupon, a motion was adopted that a Committee of the Institute be appointed to confer with the branch representatives and recommend what if any changes should be made in relationship of the branches to the Institute and to development in order that this very important part of Institute activities should have full consideration and be given the attention which it merits.

Conferences with Other Engineering Societies.

While the Board's resolution did not specifically instruct the Development Committee to confer with similar Committees from the other National Engineering Societies, the Chairman was informally advised by the President that where such conferences could expedite and help to crystalize the view point of the several organizations concerned without committing the Institute to any line of action they would be desirable. Responding, therefore, to a suggestion from the Development Committee of the American Institute of Mining and Metallurgical Engineers and to an invitation from a similar Committee from the American Society of Mechanical Engineers, Messrs. Scott, Robinson and the Chairman have conferred with representatives from the Development Committees of the American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers, and discussions are in progress relative to joint action by the several societies represented. These discussions have not as yet proceeded far enough to indicate what if any recommendations to the several governing bodies may be agreed upon but it is gratifying to be able to report progress and state that the spirit of cooperation manifested by the other conferees is a good omen.

All of which is respectfully submitted,

COMMITTEE ON DEVELOPMENT,

CALVERT TOWNLEY,
Chairman.

August 12, 1919.

BOARD OF DIRECTORS, 1919-1920.

PRESIDENT.

(Term Expires July 31, 1920)

CALVERT TOWNLEY

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(Term expires July 31, 1920)
E. W. RICE, Jr.

(Term expires July 31, 1921)
COMFORT A. ADAMS

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(Terms Expire July 31, 1920)

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*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK JULIAN SPRAGUE, 1892-3.
*EDWIN J. HOUSTON, 1893-4-5.
*LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-02.
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN W. LIEB, 1904-5
SCHUYLER SKAATS WHEELER, 1905-6
SAMUEL SHELDON, 1906-7.
*HENRY G. STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09.
LEWIS B. STILLWELL, 1909-10
DUGALD C. JACKSON, 1910-11.
GANO DUNN, 1911-12.
RALPH D. MERSHON, 1912-13.
C. O. MAILLOUX, 1913-14.
PAUL M. LINCOLN, 1914-15.
JOHN J. CARTY, 1915-16.
H. W. BUCK, 1916-17.
E. W. RICE, Jr., 1917-18.
COMFORT A. ADAMS, 1918-19.

*Deceased.

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Revised to September 1, 1919.

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George A. Hamilton,
L. F. Morehouse,
W. I. Slichter,
C. E. Skinner.

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L. F. Morehouse.

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Columbia University, New York.
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E. E. F. Creighton,
John H. Finney,
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Chairman of Committee on Technical Activities and the chairmen of all technical committees.

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and the chairmen of all Institute Sections *ex-officio*.

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A. E. Kennelly, Secretary,
Harvard University, Cambridge, Mass.
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B. A. Behrend,
James Burke,
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H. M. Hobart,
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W. S. Moody,
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S. W. Stratton,
Elihu Thomson,
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PROCEEDINGS
OF THE
American Institute of Electrical Engineers

Vol. XXXVIII
Number 10

OCTOBER, 1919

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TABLE OF CONTENTS

Section I.—Institute Affairs

Joint A. I. E. E. and I. R. E. Meeting in New York 355
Philadelphia Meeting, Friday and Saturday, October 10 and 11, 1919 355
Past Section Meetings 356
Standardization as an Aid to World Peace 356
Naval Radio Stations for Commercial Use 358
Technical Men for the Consular Service 358
Engineering Council 359
  U. S. Topographic Map 359
  Classification and Compensation of Engineers 360
  Laws for Licensing of Engineers 361
Engineering Service Bulletin 362
Engineering Societies Library 365
Personal 367
Obituary 367
Applications for Election 367

Section II.—Papers and Reports

Transatlantic Radio Communication. By E. F. W. Alexanderson, New York, October 1, 1919 1077
Principles of Radio Transmission and Reception with Antenna and Coil Aerials. By J. H. Dellinger, New York, October 1, 1919 1095
A Report on Electromagnetic Induction. By S. J. Barnett, Philadelphia, Pa., October 10, 1919 .. 1151
The Positions of Atoms in Metals. By A. W. Hull, Philadelphia, Pa., October 10, 1919 1171
The Vacuum Tube as a Generator of Alternating-Current Power. By John H. Morecroft and H. Trap Friis, Philadelphia, Pa., October 10, 1919 1193

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JOINT A. I. E. E. AND I. R. E. MEETING IN NEW YORK

A joint meeting of the American Institute of Electrical Engineers and the Institute of Radio Engineers will be held in the Auditorium of the Engineering Societies Building, 33 West 39th Street, New York, on October 1, 1919, at 8:15 p. m.

Three papers will be presented as follows:

1. *Trans-Oceanic Radio Telegraphy*, by E. F. W. Alexanderson, of the General Electric Co.
2. *Telephone Repeaters*, by F. B. Jewett of the Western Electric Co. and B. Gherardi of the A. T. & T. Co.
3. *Principles of Radio Transmission and Reception with Antenna and Coil Aerials*, by J. H. Dellinger, of the Bureau of Standards.

PHILADELPHIA MEETING FRIDAY AND SATURDAY OCTOBER 10-11, 1919

A joint meeting of the A. I. E. E. and the A. P. S. will be held in Philadelphia at the Bellevue-Stratford Hotel on Friday and Saturday, October 10-11, 1919.

There will be a session of the American Physical Society Friday morning, a session of the American Institute of Electrical Engineers Friday afternoon, a Subscription dinner Friday at 6:00 p. m. and a joint session of the two societies Friday evening.

On Saturday morning there will be a session of the American Physical Society at the Leeds & Northrup Plant following an inspection of the plant, Saturday noon, a complimentary luncheon given by the Leeds & Northrup Company, followed by an automobile ride about Germantown. On Saturday afternoon there will be a regular session of the American Physical Society.

Opportunities will be afforded for technical excursions to the Welsbach factory and for steamer rides down the Delaware River.

Members of each society are cordially invited to participate in the sessions of the other society.

PROGRAM

Friday

9:00 a. m. to 2:30 p. m. (Clover Room)
Registration of Members and Guests.

9:00 a. m. (Clover Room)
Session of the Physical Society

Atomic Structure. Paper by P. W. Bridgeman and Irving Langmuir. Discussion by Saul Dushman and others. It is intended to make this interesting to engineers as well as physicists.

10:30 a. m. (Blue Room)
A. I. E. E. Board of Directors' Meeting.

2:30 p. m. (Clover Room)
Session of the A. I. E. E.

1. *The Arrangement of Atoms in Metals*, by Dr. A. W. Hull of the General Electric Research Laboratory. An X-ray study of crystal structures, a demonstration with models of crystals will be shown. (Written for engineers.)

2. *The Oscillating Vacuum Tube as a Generator of Electrical Power*, by Professor J. H. Morecroft and H. T. Friis both of Columbia University. Lantern slides of oscillograph records.
3. *Electromagnetic Induction*, by Dr. S. J. Barnett of the Carnegie Institute, Washington.
4. *Piezo Electric Effect*, by A. M. Nicholson of the Western Electric Company. (Demonstration).

6:00 p. m. (Stratford Room)

Informal Dinner. $2.50 per person. Short talks by the Presidents of both Societies.

8:00 p. m. (Clover Room)

Joint A. I. E. E. and A. P. S. Session

Technical papers by Prof. H. A. Bumstead of Yale University, and Mr. J. J. Carty, Vice-president of the American Telephone and Telegraph Company.

Saturday

10:00 a. m.

Session of the Physical Society

Inspection of the Leeds and Northrup Company's plant.

Two semi-technical papers by the Research Laboratories of the Leeds and Northrup Co.

12:00 noon

Complimentary Luncheon by the Leeds and Northrup Company.

Automobile ride about Germantown.

2:30 p. m.

Session of the American Physical Society, Regular American Physical Society Papers.

Entertainment

There will probably be opportunity for technical excursions to the Welsbach factory or a steamer ride on the Delaware River to Chester at 10:30 Friday morning. The steamer ride will be available Saturday morning also.

Committee Meetings

Several A. I. E. E. Committee meetings will be held in accordance with notices sent to committee members.

PAST SECTION MEETINGS

Lynn.—July 23, 1919, 42 Center Street, West Lynn. Address by Professor Elihu Thomson on "Mars and Its Inhabitants." Attendance 98.

Panama.—July 27, 1919, U. S. S. New Mexico. Inspection trip to the U. S. S. New Mexico anchored in Panama Bay. Attendance 235.

August 31, 1919, Mount Hope. Inspection trip to the New Cold Storage and Ice Manufacturing Plant. Attendance 50.

STANDARDIZATION AN AID TO WORLD PEACE

At the dinner given in honor of Mr. Charles LeMaistre, Secretary of the British Engineering Standards Association, by the American Engineering Standards Committee, the guest of the evening expressed the opinion that one of the strongest ties which c[illegible] bind two or more nations together [illegible] ring and industrial standardi[illegible]

This, the first functio[illegible] en by the American Engin[illegible] ndards Committee, took pla[illegible] ngineer's Club, New Yor[illegible] Thursday evening Septemb[illegible] It was attended by more [illegible] ty engineers representing practically every organization interested in the development of standards.

Responding to the invitation of Chairman Comfort A. Adams, who acted as Toastmaster, Mr. LeMaistre said in part:

"Human language is but a very poor interpreter of the highest thoughts of the human mind and I must plead with you and ask your indulgence as I can only be but a poor interpreter of the very high ideals which the British

Engineering Standards Association has always set before it. The B. E. S. A. was formed in 1901 at the instance of Sir John Wolfe Barry, the doyen of our engineering profession, and it was through his able guidance during some sixteen years of the most important period of its existence that the Association gradually gained the confidence of the people. We are now an organization of some three hundred committees and twelve hundred members who give their time fully to the work."

"Though much of the work of our committees is done in London many of them meet in the centers where the particular standard under discussion is manufactured. This assures at the very outset that those people who are going to use the standards and who are in daily contact with the apparatus involved, and who have the closest knowledge of the details, shall put up the first proposals. This is not quite what we used to do but we realize more and more that standardization is, shall I say, 15 per cent technical and 85 per cent human. Standardization is an industrial matter and it is the industry that should put up the standards and get the help of the engineers and experts to support them."

"I hardly like to go into a discussion of the general principles of standardization because I should feel that I was talking to my masters. However, we agree that standardization means efficient production. It can only be effective when overlapping is avoided. Overlapping can only be obviated by the operation of some central organization, which we have provided in Great Britain with wonderful effect. We find now that overlapping of effort is becoming less and less each year and the B. E. S. A. is becoming more and more recognized as the central authority for drawing up standards for engineering and allied industries."

"During the last year or two I have received at my office numbers of letters from America inviting cooperation and I have always been in some difficulty to know how to reply. Take for instance the Electrical industry which has in this country at least a dozen organizations doing standardizing work. A request from one of these could not be accepted as from all. My association feels that, at the present important stage of the development of the work and of the closer relationship with the United States, if only we could get coordination of standardization on both sides of the water, one central authority on each side, it would not only help our industries enormously, but we could work hand in hand on these technical problems which involve this complicated human factor. And in doing this big work we would surely be no mean influence in promoting the peace of the world."

Following Mr. LeMaistre's address Chairman Adams called for responses from the representatives present. Dr. C. O. Mailloux spoke as the Chairman of the American Committee of the International Electrotechnical Commission, and as a close friend and admirer of Mr. LeMaistre. Mr. Nelson P. Lewis, past president and representative of the American Society of Civil Engineers, pledged the support of his Society of the contemplated development of the American Committee. Professor Charles F. Scott, representing the American Institute of Electrical Engineers, reviewed the beginnings of electrical standardization in America which he regarded as the basis of international electrical standardization accomplished so far. Mr. Edwin M. Herr represented The American Society of Mechanical Engineers and also spoke for this Society. Mr. Guilliaem Aertsen of the American Society for Testing Materials introduced a pleasing analogy to emphasize the necessity for developing team work which helps not only the team but the individual as well.

Dr. S. W. Stratton, Director of the Bureau of Standards, reiterated the readiness of the Government Departments to cooperate in the development of the Committee's program, and Mr. Charles M. Manly, President of the Society of Automotive Engineers, pledged his Society. Mr. Ira H. Woolson represented the National Board of Fire Underwriters, Mr. A. Cressy Morrison spoke for the National Safety Council, Mr. G. H. Ramsdell told of the standardization work of the American Gas Association. Mr. B. F. Waterman represented the American Gear Manufacturers Association, Mr. Charles W. Baker spoke for the Technical Press, and Mr. D. Knickerbacker Boyd told of the great need of standardization in building materials and design.

NAVAL RADIO STATIONS FOR COMMERCIAL USE

A bill has been introduced in the House whereby the Secretary of the Navy is to be authorized to permit the use of radio stations under the control of the Navy Department for transmission and reception of commercial messages for the immediate benefit of American maritime, press and other interests. The Secretary is to prescribe regulations under which the naval stations will handle these messages, and he is to fix rates for same. News messages for news associations, etc., are not to exceed five cents per word between the Philippine Islands, the Hawaiian Islands and other Pacific and South Pacific islands, and the west coast of the United States. They are not to exceed the rate of six cents per word between Asia, Asiatic Islands and the west coast of the United States. Press and commercial messages shall be entitled to as speedy transmission as the interests of the government will permit.

The use of the Navy Department stations is not to be permitted where American owned and operated private radio stations of adequate power for transmitting messages are maintained and operated. Receipts from such service are to be turned into the Treasury as miscellaneous receipts.

TECHNICAL MEN FOR THE CONSULAR SERVICE

For the coming consular examinations the officials of the State Department have expressed their hope that a considerable number of technical men will take the examination. The Department recognizes that the interest of the United States will be served best if technical men are made available through these examinations for vacancies at points where their training will be of special value.

The salaries in this service have been notoriously unattractive, and the Department recognizes that the salary scale is more inadequate now than it ever has been, as a result of which the United States has lost much prestige in many communities where properly qualified Americans cannot be induced to accept positions. They now want retired engineers and other technical men who are in a position to put something into the service to take these consular examinations in which they can undoubtedly qualify for the best positions obtainable.

The industrial engineers who had passed the consular examination would be assigned to industrial centers of Europe or South America. Mining engineers, chemists, electrical engineers, etc., would be assigned to industrial centers requiring special training.

The consular examinations will be held in the late fall or early winter. No definite date has been fixed as yet.

ENGINEERING COUNCIL

U. S. Topographic Map.—On July 1 the Chairman of Engineering Council addressed a letter to President Wilson, an abstract of which follows:

Every industry, art and science, governmental or otherwise, which demands a knowledge of the lay of the land is dependent on suitable maps. The location of railways and highways; the planning of irrigation, drainage, and water supply projects; the prosecution of geological, soil and forest surveys; the development of water powers and the installation of electric power lines; the improvement and maintenance of inland waterways and the location of reservoir sites for flood relief and water conservation—all require good maps. If none are available special maps must be made with consequent increase of cost and loss of time, or the projects must be pursued with uncertainty.

By the word "map" is meant a topographic or relief map which gives a record of land elevations by contour lines, and all of the physiographic and cultural detail necessary to an accurate picture.

The official map work of the United States is now being prosecuted by twelve separate and distinct Federal agencies, the majority of which are making maps for special purposes, which maps are of little value for any other purpose. We are confident that if the aggregate efforts of Government were coordinated on the making of a base map of suitable accuracy and scale, it would serve for all Governmental as well as private purposes and could be adapted without great expense to any special or unusual purpose. The amount of money now being expended would, if converted into a well-coordinated mapping plan, produce better and more useful results than that which now can be shown by the aggregate production of all Government map-making agencies.

In addition to Government surveys some states, counties, cities and private organizations are engaged in this work. Each of the Federal agencies and the others above mentioned follows methods developed in its own surveys and the result is precisely that which might be expected. There is no agency in the United States which has authority to coordinate the work.

Engineering Council believes that the chaotic condition above described is wrong. It makes this presentation to the Executive because he is the one authority having jurisdiction over all of the Federal agencies above mentioned. It is the opinion of Council that the most purposeful way to bring order into map making and to expedite the completion of our topographic map is to appoint a "Board of Surveys and Maps" consisting of a representative from each of the present Federal map-making agencies, together with representatives from well-qualified map using agencies, which would be vested with authority to work out a plan of standardization and coordination of the work of the Government, and to report the same to the President for such action as he may find wise.

In order to give further definition to the present petition and to facilitate your consideration thereof, Engineering Council suggests the following unofficial bodies as the proper ones to participate in the work of the Board: American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, American Society of Mechanical Engineers, American Institute of Electrical Engineers, American Association of State Geologists, National Research Council, American Association of State Highway Officials, and Engineering Council.

On August 27th a reply was received from President Wilson in which he stated he would arrange a conference for giving the matter most serious consideration.

The President directed the Secretary of War to call such a conference and General Black, Chief of Engineers, arranged this meeting for September 15th with representatives from the following Government offices:—Corps of Engineers, U. S. Coast & Geodetic Survey, U. S. Geological Survey, General Land Office, Post Office Department, Bureau of Soils, Reclamation Commission, Bureau of Roads, Indian Office, Mississippi River Commission, Survey of the Great Lakes and the Boundary Commission.

A resolution was adopted, declaring that a program of larger expenditure is imperative and that the coordination of existing map making activities is a necessary step if the public funds are to be used economically.

The chairman was authorized to invite to a future meeting representatives from Engineering Council, American Association of State Geologists, American Association of State Highway Officials, National Research Council, Geological Society of America, Association of Geographers, American Geographic Society and National Geographic Society. The representatives of those organizations will be asked to attend the meeting for the purpose of presenting to the Government representatives the various needs of map users.

Sub-committees of the main committee were later appointed. It will be the duty of these sub-committees to report back to the main committee, following which the representatives from engineering organizations will be called into conference.

Classification and Compensation of Engineers.—Supplementing the preliminary report of the Committee on Classification and Compensation of Engineers of Engineering Council published in the July PROCEEDINGS, the State and Municipal Section reports in part as follows:

A "Classification of the Civil Service of Canada" authorized by the Canadian Parliament and prepared under the direction of the Civil Service Commission has been objected to, particularly on the ground that the compensations proposed for higher grades of service are inadequate. In view of the investigation now being made on behalf of Engineering Council as to the classification and compensation of engineers in Federal, State, Municipal, and Railroad service, this report is of more than usual interest.

Engineering Council's Committee on Classification and Compensation for the State and Municipal services has tentatively proposed that all positions in these services be limited to 13 in number, of which 7 are distinctly professional, while the remaining 6 are in a class directly leading to professional work, but not necessarily of a professional character. In the questionnaire recently issued by the Committee the views of the responsible heads of the services affected are being sought, and in the responses which have been received up to the present writing, there has been practically unanimous agreement on the classification. The inquiry has not progressed far enough to warrant any expression as to the views concerning compensation other than to say that there is an unquestionably strong belief that if the engineering service is to be maintained on a proper plane, there must be a very substantial increase in pay.

The Canadian report appears to cover every position in the civil service. The objections raised appear to be well found. No attempt seems to have been made to standardize titles. Consequently there are in the engineering service at least 157 independent titles as compared with the 13 titles proposed by our Committee.

The report states that the compensations proposed are intended for "normal times" and that pending restoration of such times, the rates recommended should be "supplemented by a bonus," but no information appears as to the magnitude of the bonus.

From study of the report it would appear that the groups and ranges of compensation, tabulated as far as practicable under the classification tentatively proposed by Engineering Council's Committee are about as follows:

TABULATION OF TITLES AND SALARIES FOR ENGINEERS IN CANADIAN CIVIL SERVICE RDPORT UNDER CLASSIFICATION PROPOSED BY COMMITTEE OF ENGINEERING COUNCIL.

Tentative Classification of positions in State and Municipal Service proposed by Engineering Council's Committee on State and Municipal Service.	Salary range proposed for Canadian Service	
	Min.	Max.
Consulting Engineer	$6,000	
Chief Engineer (major work)	6,000	
Chief Engineer (minor work)	3,900	$6,000
Chief Engineer—Deputy	3,900	5,700
Engineer	3,300	4,500
Senior Assistant Engineer	2,640	3,480
Assistant Engineer	2,100	3,120
Junior Assistant	1,680	2,160
Senior Draftsman	Included in Professional Service	
Draftsman	1,260	
Junior Draftsman	900	
Chief Instrumentman	Included in Professional Service	
Instrumentman	1,260	
Rodman	900	

In general, promotion through most of the grades is by increments of about $120, the minimum and maximum rates of each being respectively higher and lower than the rates fixed for the grades below and above, this resulting in a comparatively small salary range for each position and in this respect corresponding with what seems to have been the general practise heretofore. This treatment is one which it would seem desirable to modify to the end that the relative ability and experience of men performing similar work may be given adequate recognition.

Exceptions are noted in the case of "Topographical Engineer," where a salary range of from $2,160 to $3,120 is proposed, and in the case of promotion from "Junior Electrical Engineer" at a maximum salary of $1,980 to "Electrical Engineer" with a minimum salary of $2,640, each of the two latter grades having an extreme salary range of only $360. In the case of "Chief Draftsman," "Structural Engineer," and "Chief Topographical Engineer" maximum salaries are proposed of $3,000, $3,240, and $3,840, with no provision for promotion to other engineering grades, although for each position the qualifications required are such as to indicate ability to progress to high positions in the service.

The table also shows that only 6 engineering positions are open to compensation at a rate of more than $6,000 per annum.

It would seem that this report is open to serious criticism on the grounds that it fails to group engineering service along orderly lines, that it provides too narrow limits for promotions within a grade, and that the compensation proposed for all grades, is inadequate for the service rendered. The latter criticism seems particularly pertinent in comparison with the rates now being demanded by organized labor. The practicability of properly meeting present day conditions by the addition of a "Special War Bonus" to the proposed rates in order to meet the present high cost of living is also to be questioned on the ground that, and as set forth in the circular letter issued by Council's Committee on Classification and Compensation of State and Municipal Engineers, the "revolutionary change in the cost of living" is one which "unless modified by further economic disturbance is likely to be permanent or to continue for a long time to come."

Laws for Licensing of Engineers.—According to the best information obtainable by the License Committee of Engineering Council, laws providing for licensing of engineers are on the statute books of the following eleven States: Wyoming, 1907; Louisiana, 1908, (Amended 1914); California, 1908; South Dakato, 1913; Illinois, 1915; Idaho, 1915; Florida, 1917; Oregon, 1919; Colorado, 1919; Michigan, 1919; Iowa, 1919.

The License Committee is working on a draft of a typical bill which, it is intended, can be used if necessity should arise in States proposing new legislation on this subject, or in those proposing revisions so that laws enacted for licensing engineers may be uniform, or nearly so, throughout the country.

Engineering Council, however, has as yet taken no stand on the desirability of licensing or registering of engineers. It desires to learn the opinions of engineers in various branches of the profession in all parts of our country; also to secure soon all information that would be helpful to the committee.

The earnest assistance of members of the Institute is asked in getting the needed opinions and information.

Please address all letters to ALFRED D. FLINN, Secretary; Engineering Council, 29 West 39th St., New York.

ENGINEERING SERVICE BULLETIN

Opportunities.—The Institute, is particularly anxious to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in this BULLETIN. The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Services Available.—Under this heading brief announcements (not more than fifty words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office files.

Note.—Copy for publication in the BULLETIN should reach the Secretary's office not later than the 20th of the month if publication in the following issue is desired. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

Engineering Societies Employment Bureau.—This is a joint bureau under the auspices of the Engineering Council. The Institute's employment service is coordinated with that of the joint bureau.

OPPORTUNITIES FOR SERVICE

V-541. Wanted: Design Engineer experienced in modern substation and power plant layouts. Loaction New York City. Give details of experience and salary expected.

V-564. Production Manager, for Chicago works of electric motor and dynamo factory. One who is thoroughly experienced in modern production methods. Give full details of experience, age, references, etc.

V-568. Electrical Draftsman, with high grade experience in circuit and diagram work. Give details as to experience and salary desired.

V-569. Draftsmen and designers wanted by prominent manufacturing concern located in middle West. Men familiar with the design of electrical apparatus and with considerable mechanical experience preferred. Splendid opportunity for men released from the Army or Navy who have not as yet found permanent positions. In reply please cover the following information: education, experience, age and salary expected.

V-570. Canadian manufacturing concern located in Toronto, Ontario, desires services of a young man having some experience in designing panel boards and switchboards. Work consists of making practical working drawing and material lists used in construction of panels and switches. Salary $1500 per year. Good opportunity for advancement.

V-571. Wanted: Engineers with experience in the design of induction motors; also, an assistant engineer who has had experience in the design of transformers. Applicants should state qualifications and experience in detail. Location, Canada.

V-574. Graduate in electrical engineering qualified to serve as instructor, or assistant instructor, in the Dept. of

E. E. of an Eastern college. Prefer man who has had at least one year's practical experience since graduation; salary dependent upon qualifications.

V-575. We require the services of several experienced electrical testers, or young technical men desiring general test experience. Apply personally or write, giving detailed description of experience, schooling, age and nationality. Plant located at Ampere station on D. L. & W. R. R., approximately 55 minutes from New York City. Employment Dept., Crocker-Wheeler Electric Co., 4th Ave., Ampere, (East Orange), N. J.

SERVICES AVAILABLE

1415. Former Captain of Engineers available for high grade position with power or street railway property. Graduate electrical engineer, 17 years experience, civil, electrical, hydraulic, power development and irrigation, some teaching. Technical and executive ability. Now on Pacific Coast. Salary $3600.

1416. Graduate in electrical engineering course; two years experience as draftsman. Desires position with opportunity for advancement according to ability. Initial salary not important.

1417. Graduate Electrical Engineer, age 27, desires a position in the production end of engineering, with a growing manufacturer. Has had two years executive experience in general consulting department of large corporation, controlling other engineers and draftsmen, with limited production experience in small factory manufacturing intricate brass mechanisms. Salary $2500.

1418. Electrical Engineer (practical) good technical education. Nineteen years electrical experience. Five years with industrial engineering concern on isolated plant, layout and installation, five years with central station on design and construction in central and substation high-tension work; desires a responsible position. Married; age 37. Present position pays $2600.

1419. Electrical Engineer, technically trained, foreign and domestic experience, conversant in design, manufacture and production of electrical instruments, meters, relays, circuit-breakers and switching apparatus for high and low tension. Can introduce new designs. Requires responsible position. Competent to take up an interest in business. Age 37; married. Salary $3600 to $4800.

1420. Central station executive electrical engineer of 18 years experience with large urban system. Fel. A. I. E. E., Mem. N. E. L. A., E. C. S., etc., is desirous of associating himself in an engineering or managerial capacity, with a progressive property. Available after January 1.

1421. Young electrical engineer, American who can speak German; age 24; A. I. T. graduate of 1919; mechanically inclined; also radio engineer, desires position offering a good future, preferably in the western part of the United States.

1422. Electrical Engineer, age 25, single, desires change. Five years substation and power plant operation, testing; five years installation and operation street lighting and water system. Prefer similar work as plant electrical engineer or chief electrician industrial plant. Location optional. Salary $2500.

1423. College graduate electrical engineer, 26 years old, four years experience traffic and office work in large telephone and telegraph company desires an office position in New York City or vicinity in which good opportunities for advancement are offered. Excellent technical and business correspondent. Minimum salary to start $170. Available on month's notice to present employer.

1424. Electrical and Mechanical Engineer, age 37, married, university graduate E. E., Mem. A. I. E. E. Fourteen years experience, the last ten years as electrical and mechanical engineer for large mining company in charge of installation, operation and maintenance of all power plant equipment, electrical equipment, air compressors, etc. Minimum salary $3600.

1425. Electrician, technical and practical, 22 years experience. Traveled on the road for two of the largest companies, on electrical construction of power plants, industrial motor control systems, coal hoists, cranes, rolling mills, etc. Familiar with winding and commutation troubles.

1426. Graduate electrical engineer, three years experience in test room and laboratory of large electrical concern. Desires a position as electrical engineer in manufacturing or power plant work. Eastern states preferred. Salary $2400.

1427. A graduate electrical engineer of ten years experience, just returned from thirteen months overseas with the A. E. F., and now serving as a Captain of Engineers, expects to be discharged from service on September 30, desires a position on construction work, or with a live manufacturing concern.

1428. Electrical-Mechanical Engineer with five years experience in steam power plant design and construction, general construction and cost estimates. Technical graduate of proven ability. Salary $3000 per year. New York City.

1429. Technical graduate, age 25, married. Have completed an accounting course, two years General Electric and other test work, two years inspection and accounting, electrical equipment installation. Desire permanent position offering good future. Eastern location preferred.

1430. Electrical-Mechanical 1909. Students course order department, construction, sales engineer, electrical manufacturer. Service manager. Engineer and purchasing agent U. S. Government $400,000 electrical work. Desires to leave Government service. Married. Salary for past three years over $3000.

1431. Electrical Engineer, technical graduate, eight years experience in factory construction and field installation of electric machinery and turbines, and operation of power plants and transmission systems; during past two years and at present district manager of gas, water and electric properties of large holding company. Minimum salary $3000.

1432. Graduate electrical engineer. Operating experience, sub- and hydraulic generating stations on high tension system. G. E. test. Experience wide and varied in electrical power apparatus. Of analytical, ingenious and initiative mind. At present cover several states investigating and remedying trouble in application of apparatus manufactured by one of largest companies. Desire change from travelling where experience and qualifications will be of value.

1433. Electrical and Mechanical Engineer desires position as electrical construction engineer or sales engineer for power machinery. General Electric course two years; design and installation of power plants two years; two years U. S. Engineer Corps.

1434. Technical graduate, 25 years of age. Two years Westinghouse test, transformers and large rotating electrical machinery. Desires position with power company as assistant to chief electrical engineer or manager. Salary to start $2000.

1435. Electrical Engineer, graduate E. E., age 26, married, at present in engineering office. Desires position in sales engineering or "live" manufacturing concern. Has had three and half years engineering experience, also teaching experience. Minimum salary $2000 Available on short notice.

1436. Public Utility Management Engineer, eight years experience investigating, developing, and managing properties and systems from central office, recently released from two years organization and technical work as Captain, Ordnance Dept., available immediately for management of properties, or as assistant to executive of holding companies. Graduate electrical engineer, age 32, salary $3000 to $3600.

1437. Electrical Engineer Executive, age 28, ex-Captain U. S. A. Administration of 4000 men on construction. Familiar with all branches public utility work, finance and accounting. Desires position where ability to make decisions and handle new situations counts more than long years of experience in some limited field.

1438. Graduate Electrical Engineer, age 28, with four years experience in construction, testing and operation of steam and hydro-electric power plants, desires a position in growing industry where chances for advancement are good. Minimum salary $2400.

1439. Electrical Engineering graduate of 1916. Three years experience in operation and manitenance of telephone and telegraph apparatus, motors, generators, rectifiers, and storage batteries, lighting and machine power layouts, desires position. Salary depends upon chance of advancement.

1440. Technical Graduate, age 27, married, desires position as assistant to Electrical Engineer, Supt. Const., doing large business or Works Manager of electrical manufacturing company. Two and a half years testing motors and generators (a-c. and d-c.) 1 year tele. central station construction, 4 years electric wiring for light, heat and power. Also two years machine shop practice. Minimum salary $1800.

1441. Electrical Engineer, technical graduate, with broad practical engineering experience. Capable and accustomed to handling engineering problems. Eight years experience in power plants and electrical construction work. Desires responsible position with construction or operating company or consulting engineer. Ohio or adjoining states preferred. Age 36. Salary $3000. Available on reasonable notice.

1442. Able organizer and executive who has made good. At present employed; seeks position with concern wishing to lower costs and better product. Experienced in production, systematizing, costs inspection and designing labor saving appliances, including machine tools and small tools, particularly for electrical manufacturing. Age 33. Salary $10,000.

1443. Electrical Engineer, engaged in hydroelectric design, construction and operation in South America, will consider change to company where free hand is given. Technical training with fifteen years' experience in hydroelectric field. Available early next year. Might arrange to leave in three months. Salary $6000 in Latin America, Spain or the Philippines, or $4500 in U. S. A.

1444. Engineering graduate; seven years experience in electrical construction, test and operation of central station—150,000 kw. capacity. At present employed, but desires position with power or construction company affording opportunity for greater service and responsibility. Married, age 26. Location preferred—Pennsylvania.

1445. Technical graduate, age 33, two years General Electric test, seven years experience in operation, testing and installing, foreman of test past six months with prominent electric manufacturing company. Available on short notice. Salary $2400.

ENGINEERING SOCIETIES LIBRARY

The library, which comprises the individual libraries of the American Institute of Electrical Engineers, the American Society of Mechanical Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Civil Engineers, and the United Engineering Society, is located on the thirteenth and fourteenth floors of the Engineering Societies Building. In addition to engineering works it contains general reference books on allied sciences such as Physics, Mathematics and Chemistry. The library also contains publications of practically all the engineering societies in the world as well as current and bound sets of more than 1,000 engineering periodicals in English and other languages.

In order to place the facilities of this great engineering library at the disposal of persons residing out of town, a Library Service Bureau has been established, and a staff of expert searchers and translators is prepared to cover almost any engineering topic. Charges for service are at actual cost. Ph tostat copies of prints, drawings, etc., are $0.25 per 10 x 14 inch sheet.

All communications should be made as definite as possible so that the information received may be what is desired and not include collateral matter of no interest. The time spent in searching for such collateral matter will be saved, and information sent more promptly and in more usable shape.

Members who may desire it will be kept informed regarding current publications on any engineering subject for a small annual fee.

The library is conducted as a free public library of reference. It is open to the public from 9 a m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a.m. to 6 p.m.

Book Notices.—(August 1–August 31, 1919) Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

BOILER FEED WATER:

A Concise Handbook of Water for Boiler Feeding Purposes (Its Effects, Treatment, and Analysis). By Percy G. Jackson. Lond., Charles Griffin & Co., Ltd.; Philadelphia, J. B. Lippincott Co., 1919. 102 pp., 7 x 5 in., cloth, $2. (Gift of J. B. Lippincott Company).

CONTENTS: Mineral Constituents—Corrosion—Softening—Selection of Softening Plates—Priming—Scale, Grease, and Overheating—Methods of Analysis—Analysis of Scale—Control Tests for Water Softening—Sampling—Solutions—Appendix: List of Factors—List of Atomic Weights—Clark's Table of Hardnesses.

This volume is intended to be a reliable, concise and practical compendium of information on boiler waters and feed water troubles. It is based on long experience as chemist to an English boiler insurance company.

ELECTRIC POWER TRANSMISSION:

Principles and Calculations, including a Revision of "Overhead Electric Power Transmission." By Alfred Still. 2nd edition. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1919. 407 pp., illus., tables, 9 x 6 in., cloth, $3.50.

"Overhead electric power Transmission" was written to provide a discussion of the fundamental principles and scientific laws determining the correct design of overhead transmission lines, suited to the needs of the office engineer in charge of calculations and specifications. The addition of a chapter on underground conductors has now made it necessary to alter the title. The work has also been thoroughly revised, obsolete matter has been omitted and new material added.

MANUAL OF THE CHEMICAL ANALYSIS OF ROCKS:

By Henry S. Washington. 3rd edition. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1919. 12 + 271 pp., 1 pl., tables, 9 x 6 in., cloth, $2.50.

The author's object is to present a selection of methods for the analysis of silicate rocks, especially those of igneous origin, adapted to the needs of chemists, mining engineers, etc., who have not made a particular study of quantitative analysis.

The present edition has been thoroughly revised and considerably enlarged.

MECHANICAL DRAWING FOR HIGH SCHOOLS.

A Text with Problem Layouts. By Thomas E. French and Carl L. Svensen. 1st edition. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1919. 221 pp., illus., tables, 9 x 6 in., cloth.

The object of this book is to present mechanical drawing as a definite educational subject by which the student's power of visualization may be developed and his constructive imagination strengthened, while he is also taught to think exactly, to understand and make mechanical drawings and to know modern drafting room practice.

The course outlined covers two years' work and is a complete textbook and book of problems.

THE NAVAL ARCHITECT'S, SHIPBUILDER'S AND MARINE ENGINEER'S POCKET-BOOK:

By Clement Mackrow and Lloyd Woolard. 12th edition. N. Y., The Norman W. Henley Publishing Co. 1918. 760 pp., illus., tables, 7 x 4 in., flexible cloth.

The twelfth edition of this pocket-book appeared two and one-half years after the eleventh, from which it differs by the correction of errors and the addition of seventeen pages containing supplementing notes on various sections of the book and an article on estimating the weight and cost of a merchant vessel.

In addition to the subjects usually discussed in such works, articles on aerodynamics and aeronautics are included.

STUDIES IN THE CONSTRUCTION OF DAMS: EARTHEN AND MASONRY.

Arranged on the Principle of Question and Answer for Engineering Students and Others. By Prof. E. R. Matthews. Lond., Charles Griffin & Company, Ltd.; Philadelphia, J. B. Lippincott Company, 1919. 43 pp., 30 illus., 9 x 6 in., paper, $1.50. (Gift of J. B. Lippincott Co.)

This book is intended for students preparing for examinations, especially those for associate membership in the Institution of Civil Engineers, or the Institution of Municipal and County Engineers, or for the degree of bachelor of science in engineering in universities.

A TEXT-BOOK OF HEAT ENGINES:

By Andrew Jamieson. Vol. 1. 18th edition. Revised by Ewart S. Andrews. Lond., Charles Griffin & Co., Ltd., 1919. 551 pp. 8 x 5 in., cloth, $3. (Gift of J. B. Lippincott Company).

This volume is a revised edition of Professor Jamieson's "Textbook on steam and steam engines." with the omission of the chapters on steam turbines and boilers. The omitted chapters, with others on thermodynamics, entropy and internal combustion engines, will appear in volume two.

PERSONAL

Clarence J. Berry who for the last six years has been connected with National Lamp Works of G. E. Company, Cleveland, has resigned and accepted a position as electrical engineer with Brandt and Fouilleret, Paris, France.

J. P. Schroeter, for the last two years with the School of Engineering of Milwaukee has accepted a position as designing engineer for the mechanical and electrical equipment of the new food plant to be erected by the Uihlein interests on Port Washington Road, North Milwaukee. The plant is being designed by A. W. Hoffmann, 410 Berlin Arcade Building, Milwaukee.

OBITUARY

Henry A. Reed, President of the Bishop Gutta Percha Company, died at his residence, 88 North 9th Street, Newark, N. J. on August 23. Mr. Reed in the earliest days of the electrical industry assisted Prof. Morse in his telegraph experiments. In 1887 he became associated with Bishop Gutta Percha Co. as Manager. Mr. Reed was elected an Associate in the Institute in 1889 and Member in 1913.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before October 31, 1919.

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Harry Parker Gibbs, Tata Hydroelectric Power Supply Co., Ltd., Bombay, India.
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LIST OF SECTIONS

Revised to October 1, 1919

Name and when Organized	Chairman	Secretary
Atlanta.........Jan. 19, '04	A. M. Schoen	Thomas C. Taliaferro, S. E. Underwriters Ass'n., Atlanta, Ga.
Baltimore.........Dec. 16, '04	J. B. Whitehead	L.M.Potts,Industrial Bldg.,Baltimore,Md.
Boston.........Feb. 13, '03	I. E. Moultrop	Ira M. Cushing, 84 State St.,Boston,Mass
Chicago.........1893	A. F. Riggs	A. C. King, 8 So. Dearborn St., Chicago, Ill.
Cleveland.........Sept. 27, '07	B. W. David	W. D. Smoot, Willard Storage Battery Co., Cleveland, Ohio.
Denver.........May 18, '15	H. S. Evans	R. B. Bonney, 603 Wyoming Bldg., Denver, Colo.
Detroit-Ann Arbor.........Jan. 13, '11	J. C. Parker	C. E. Wise, 845 Book Bldg., Detroit, Mich.
Erie.........Jan. 11, '18	J. C. Barry	P. B. Mansfield, Lawrence Park, Erie, Pa.
Fort Wayne.........Aug. 14, '08	C. I. Hall	O. B. Rinehart, 1211 W. Jefferson Street, Fort Wayne, Ind.
Indianapolis-Lafayette .Jan. 12, '12	Gordon E. Varney	D. C. Pyke, Public Service Commission, State House, Indianapolis, Ind.
Ithaca.........Oct. 15, '02	Alexander M.Gray	John G. Pertsch, Jr., Cornell Univ.,Ithaca, N. Y.
Kansas City, Mo.........Apr. 14, '16	W. F. Barnes	W. F. Barnes, 1012 Baltimore Ave., Kansas City, Mo.
Los Angeles.........May 19, '08	Clem A. Copeland	R. W. Sorensen, Throop College of Technology, Pasadena, Cal.
Lynn.........Aug. 22, '11	A. K. Warren	Fred E. Ewart, General Electric Company, West Lynn, Mass.
Madison.........Jan. 8, '09	C. M. Jansky	L. E. A. Kelso, University of Wisconsin, Madison, Wis.
Milwaukee.........Feb. 11, '10	H. P. Reed	F. J. Mayer, Wisconsin Tel. Co., Milwaukee, Wis.
Minnesota.........Apr. 7, '02	Meyer Barnert	J. D. Marshall, 510-3rd Ave., So., Minneapolis, Minn.
Panama.........Oct. 10, '13	Wm. T. O'Connell	M. P. Benninger, Box 174, Balboa Heights, C. Z.
Philadelphia.........Feb. 18, '03	C. E. Clewell	Ross B. Mateer, Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.
Pittsburgh.........Oct. 13, '02	J. G. Carroll	W. L. Shafer, Rm. 522, 416-7th Ave., Pittsburgh, Pa.
Pittsfield.........Mar. 25, '04	R. E. Wagner	N.F.Hanley.Gen.Elec.Co.,Pittsfield,Mass.
Portland, Ore.........May 18, '09	W. D. Scott	E. H. LeTourneau, Portland Ry. Lt. & Pr. Co., Portland, Oregon.
Rochester.........Oct. 9, '14	R. H. Manson	W. C. Freeman, Stromberg Carlson Telephone Mfg. Co., Rochester, N. Y.
St. Louis.........Jan. 14, '03	J. L. Hamilton	H. G. Hake, Washington University, St. Louis, Mo.
San Francisco.........Dec. 23, '04	W. G. Vincent	A. G. Jones, 809 Rialto Building, San Francisco, Cal.
Schenectady.........Jan. 26, '03	C. S. Van Dyke	L. F. Millham, General Electric Company, Schenectady, N. Y.
Seattle.........Jan. 19, '04	J. Harisberger	T. C. Smith, Lighting Dept., Seattle, Wash.
Spokane.........Feb. 14, '13	J. E. E. Royer	Foster Russell, 1405 Old National Bank Bldg., Spokane, Wash.
Toledo.........June 3, '07	W. A. Hill	Max Neuber, 1257 Fernwood Ave., Toledo, Ohio.
Toronto.........Sept. 30, '03	Ashton B. Cooper	Daniel M. Fraser, Canadian General Electric Co., Toronto, Ont.
Utah.........Mar. 9, '17	Markham Cheever	H. T. Plumb, General Electric Co., Newhouse Bldg., Salt Lake City, Utah.
Urbana.........Nov. 25, '02	A. R. Knight	E. H. Waldo, Univ. of Illinois, Urbana,Ill.
Vancouver.........Aug. 22, '11	R. F. Hayward	T. H. Crosby, Canadian Westinghouse Co. Vancouver, B. C.
Washington, D. C.........Apr. 9, '03	Milton M.Flanders	R. Karl Honaman, Bureau of Standards, Washington, D. C.

Total 34

LIST OF BRANCHES

Name and when Organized	Chairman	Secretary
Agricultural and Mech. College of Texas.........Nov. 12, '09	F. V. Murrah	C. R. Drake, A. & M. College of Texas, College Station, Tex.
Alabama Poly. Inst.........Nov. 10, '16	W. W. Hill	E. E. Terry, Alabama Polytechnic Inst., Auburn, Ala.
***Alabama, Univ. of**.........Dec. 11, '14		
Arkansas, Univ. of.........Mar. 25, '04	Wm. L. Teague	B. R. Askew, 240 Arkansas Ave., Fayetteville, Ark.
Armour Institute.........Feb. 26, '04	E. H. Arnold	M. F. Bacon, 3408 Michigan Ave., Chicago, Ill.
Brooklyn Poly. Inst.........Jan. 14, '16	E. A. Demonet,Jr.	Thos. C. Schwab, Polytechnic Institute, Brooklyn, N. Y.
Bucknell University.........May 17, '10	C. J. Anthor	H. H. Angell, Bucknell University, Lewisburg, Pa.
California, Univ. of.........Feb. 9, '12	A. E. McMahon	D. D. Davis, University of California, Berkeley, Cal.
Carnegie Inst. of Tech..........May 18, '15	L. C. Young	B. C. Dennison, Carnegie School of Technology, Pittsburgh, Pa.
Cincinnati, Univ. of.........Apr. 10, '08	C. S. Meyer	Chas. B. Hoffmann, University of Cincinnati, Cincinnati, O.
Clarkson Col. of Tech..........Dec. 10, '15		
Clemson Agric. Col.........Nov. 8, '12	J. W. Conyers	P. L. Tollison, Clemson College, S. C.

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Colorado State Agricultural College .... Feb. 11, '10		
Colorado, Univ. of ..... Dec. 16, '04	A. S. Anderson	T. C. Smith, 1153 Pleasant St., Boulder, Colo.
Drexel Institute .... Apr. 11, '19	L. R. Culver	F. J. Hartmann, Drexel Institute, Philadelphia, Pa.
Georgia School of Technology .... June 25, '14	R. S. Griffith	G. L. Jones, Georgia School of Technology, Atlanta, Ga.
***Idaho, Univ. of** .... June 25, '14		
***Iowa, Univ. of** .... May 18, '09		
Kansas State Agr. Col. .. Jan. 10, '08	J. S. Gulledge	H. C. Lucas, Kansas State Agri. Coll., Manhattan, Kans.
***Kansas Univ. of** ...... Mar 18, '08		
Kentucky, State Univ. of Oct. 14, '10	A. D. Hall	C. A. Timmer, 315 S. Limestone, Lexington, Ky.
Lafayette College ...... Apr. 5, '12	Frank Wilson Ross	Chas. Spencer Allen, 909 Northampton, St., Easton, Pa.
Lehigh University ...... Oct. 15, '02	E. T. Petrik	F. G. Macarow, Lehigh University, S. Bethlehem, Pa.
Lewis Institute .... Nov. 8, '07		
Maine Univ. of .... Dec. 26, '06	R. C. Hopkins	L. R. Douglass, University of Maine, Orono, Me.
Massachusetts Inst. of Tech. .... Apr. 13, '17	Harmon B. Deal	Florence Fogler, Mass. Inst. of Tech., Cambridge, Mass.
Michigan Agric. Coll. .. Mar. 15, '18	R. D. Wyckoff	R. B. Kling, Michigan Agri. College, East Lansing, Mich.
Michigan, Univ. of ..... Mar. 25, '04	L. M. Ilgenfritz	Ross Gunn, University of Michigan, Ann Arbor, Mich.
Minnesota, Univ. of .... May 16, '16	Norman Kingsley	Clarence L. Nelson, University of Minnesota, Minneapolis, Minn.
Missouri Univ. of ...... Jan. 10, '03	A. C. Lanier	W. H. Moore, University of Missouri, Columbia, Mo.
Montana State Col. .... May 21, '07	Jas. M. McElwee	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of ..... Apr. 10, '08	Olin J. Ferguson	Oskar E. Edison, University of Nebraska, Lincoln, Nebraska.
North Carolina Col. of Agr. and Engg. .... Feb. 11, '10		J. G. Leonard, N. C. College of Agri. and Engg., West Raleigh, N. C.
North Carolina, Univ. of. Oct. 9, '14	W. E. Merritt, Jr.	John E. Lear, Chapel Hill, N. C.
North Dakota, Univ. of. Feb. 15, '17		
***Norwich University** ... June 28, '16		
Notre Dame, Univ. of .. Feb. 19, '19	James M. Reid	J. A. Caparo, University of Notre Dame, Notre Dame, Ind.
Ohio Northern Univ. ... Feb. 9, '12	Mark Jepson	W. L. Lynde, Ohio Northern University, Ada, Ohio.
Ohio State University .. Dec. 20, '02	R. L. Shumaker	G. E. Park, Ohio State University, Columbus, Ohio.
***Oklahoma Agricultural and Mech. Col.** ...... Oct. 13, '11		
Oklahoma, Univ. of .... Oct. 11, '12		
Oregon Agr. Col. .... Mar. 24, '08	A. L. Manning	Ray Avrit, Oregon Agricultural College Corvallis, Ore.
Penn. State College .... Dec. 20, '02	E. W. Taylor	C. K. Mast, Pennsylvania State College, State College, Pa.
Penn., Univ. of .... Apr. 11, '19	W. H. McIntyre	J. M. Ryan, Univ. of Pennsylvania, Philadelphia, Pa.
Pittsburgh, Univ. of ... Feb. 26, '14	L. P. Kennedy	H. Q. Chan, University of Pittsburgh, Pittsburgh, Pa.
Purdue University ..... Jan. 26, '03	L. A. Malott	T. K. Hartley, Purdue Univ. Lafayette Indiana.
Queen's University (Ont.) Jan. 11, '18		
Rensselaer Poly. Inst. .. Nov. 12, '09	W. J. Williams	L. B. Raynor, Rensselaer Polytechnic Inst. Troy, N. Y.
***Rose Polytechnic Inst.** .. Nov. 10, '11		
***Stanford Univ.** .... Dec. 13, '07		
Syracuse Univ. .... Feb. 24, '05	W. P. Graham	Rich D. Whitney, Syracuse University, Syracuse, N. Y.
***Texas, Univ. of** .... Feb. 14, '08		
Throop College of Technology .... Oct. 14, '10	Mark Sawyer	Russell Otis, Throop College of Technology, Pasadena, Cal.
Virginia Polytechnic Institute .... Jan. 8, '15	J. A. Carr	L. D. Pry, Virginia Polytechnic Inst., Blacksburg, Va.
Virginia, Univ. of ...... Feb. 9, '12	J. E. B. Stuart	J. Arthur Evans, University of Virginia, University, Va.
Wash. State Col. of .... Dec. 13, '07	C. E. Guse	Ralph C. Guse, State College of Washington, Pullman, Wash.
Washington Univ. .... Feb. 5, '04	W. J. Skrainka	H. T. Lange, Washington University, St. Louis, Mo.
Washington, Univ. of .. Dec. 13, '12	J. R. Tolmie	Glen H. Walker, University of Washington, Seattle, Wash.
West Virginia Univ. ..... Nov. 13, '14		
***Worcester Poly. Inst.** .. Mar. 25, '04		
Yale University .... Oct. 13, '11	P. C. O'Brien	Donald F. Hine, 114 Whitney Ave., New Haven, Conn.

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To the Members of the
American Institute of Electrical Engineers:

The Washington office of the Engineering Council was established last January for the benefit of the engineering profession of America. This office is in contact with the various departments of the Government and keeps abreast of legislation relating to matters in which engineers are concerned in connection with the practise of their profession. It endeavors to keep the engineering profession prominently before the legislative and executive branches and seeks to secure the appointment of engineers to all those places which have engineering functions. Finally, it maintains a legislative and departmental service which is supplied to the technical press and to engineers individually. Any engineer who desires a copy of a bill or information upon any bill that is being discussed in Congress, or has need of data of any kind issued by a Government Bureau, has only to ask the Washington office for the information or material. These will be supplied, if available, and no charge will be made.

While many engineers have taken advantage of this information service, the Washington office of Engineering Council is equipped to supply information to a much larger number. It is the desire of Engineering Council to extend the service in order to render the greatest possible aid to the engineers of America. All engineers are invited to use the facilities afforded by the organization at Washington and can be assured that they will receive careful attention and that every effort will be made to meet to the fullest extent any demands that may be made.

M. O. LEIGHTON, Chairman,
National Service Committee

PROCEEDINGS
OF THE
American Institute of Electrical Engineers

Vol. XXXVIII
Number 11

NOVEMBER, 1919

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TABLE OF CONTENTS

Section I.—Institute Affairs

Institute Meeting in New York, November 14 377
Future A. I. E. E. Meetings 377
A. S. C. E. Meeting, November 5 377
Meeting of Radio Engineers 378
National Drainage Congress 378
Joint Meeting in New York, October 1 378
Meeting in Philadelphia, October 10-11 378
A. I. E. E. Directors Meeting, October 10, 1919 380
Method of Financing Sections 380
Past Section Meeting 381
Past Branch Meeting 381
I. E. C. Meeting, London, October 20-24 382
The Vail Library at M. I. T. 382
Engineering Council 383
  Classification and Compensation of Engineers 383
  Boston-Washington Super Power Line 384
  Utilization of Culm 384
  Engineers in the 1920 U. S. Census 385
  Engineering Council Joins National Chamber of Commerce 385
  Report of Conference of Federal Map Making Organization 386
  Notes from National Service Committee 387
    International Communication 387
    Machine Tools for Technical Institution 387
    Steel Basing Point 387
    Commercial Testing at Government Arsenals 387
    Water Power 388
    Engineering Councils Hearing before National Budget Committee 388
    Petroleum Research Work 389
National Safety Council 390
Airplane Antenna Constants 390
Motor Transport Training Schools of the Army 390
Industrial Relations 390
Engineering Service Bulletin 391
Engineering Societies Library 397
Personal 400
Obituary 401
Addresses Wanted 401
Associates Elected, October 10, 1919 401
Associates Reelected, October 10, 1919 406
Members Elected, October 10, 1919 406

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TABLE OF CONTENTS—Continued

Transferred to Grade of Member, October 10, 1919 .... **407**
Transferred to Grade of Fellow, October 10, 1919 .... **407**
Recommended for Transfer **407**
Students Enrolled, October 10, 1919 .... **408**
Applications for Election **408**
Report of Special Committee on Publications **410**
Report of Joint Conference Committee of the Development Committee **413**

Section II.—Papers and Reports

Present Limits of Speed and Power of Single-Shaft Curtis Steam Turbines. By Eskil Berg, New York, November 14, 1919 .... **1223**
Present Limits of Speed and Output of Single-Shaft Turbo Generators. By F. D. Newbury, New York, November, 14, 1919 .... **1233**
Present Limits of Speed and Power of Single-Shaft Steam Turbines. By J. F. Johnson, New York, November 14, 1919 .... **1243**
Telephone Repeaters. By Bancroft Gherardi and Frank B. Jewett, New York, October 1, 1919 **1255**
The Piezo Electric Effect in the Composite Rochelle Salt Crystal. By A. McL. Nicolson, Philadelphia, Pa., October 9, 1919 .... **1315**

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GEORGE R. METCALFE, Editor.

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American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXVIII NOVEMBER, 1919 Number 11

INSTITUTE MEETING IN NEW YORK, NOVEMBER 14, 1919

The 355th regular meeting of the A. I. E. E. will be held in the fifth floor assembly room of the Engineering Societies Building, 33 West 39th Street, New York, on Friday evening, November 14, at 8:15 p. m.

The meeting is under the auspices of the Power Stations Committee and the general subject of the papers will be Limitations in the Design of Steam Turbines. Three papers will be presented as follows:

Present Limits of Speed and Output of Single-Shaft Turbo Generators, by F. D. Newbury of the Westinghouse Electric and Manufacturing Co.

Present Limits of Speed and Power of Single-Shaft Steam Turbines, by J. F. Johnson of the Westinghouse Elec. & Mfg. Co.

Present Limits of Speed and Power of Single-Shaft Curtis Steam Turbines, by Eskil Berg, of the General Electric Company.

The papers are published in this issue of the PROCEEDINGS and advance copies are available upon request. A thorough discussion on this timely subject is anticipated.

FUTURE A. I. E. E. MEETINGS

A tentative schedule of meetings of the A. I. E. E. for season of 1919-1920 was adopted by the Meetings and Papers Committee at its meeting in Philadelphia, October 10, as follows:

December 12, 1919, New York. Subjects: Searchlights in the U. S. Navy, and Automatic Switching for Telephone Service.

January 9, 1920, Chicago. Meeting under the auspices of the Lighting and Illumination Committee. Subject: Series, Multiple and Mixed Systems of Street Lighting.

February 18 to 20, New York. Mid-winter Convention.

March 12, 1920, Pittsburgh. Meeting under auspices of Traction and Transportation Committee. Subject: Electric Traction.

April 9, 1920, Boston. Joint Meeting with the American Electrochemical Society. Meeting under auspices of Committee on Electrochemistry and Electrometallurgy.

May 21, 1920, New York. Annual business meeting of the Institute.

June 22 to 25, 1920. Annual Convention.

A. S. C. E. MEETING NOVEMBER NOVEMBER 5, 1919

A regular business meeting of the American Society of Civil Engineers to be held in the auditorium of the Engineering Societies Building, New York, on Wednesday, November 5, 1919 at 8:30 p. m. will be devoted to a discussion on "The Compensation of Engineers."

The subject will be presented by Arthur S. Tuttle, Chairman, of Engineering Councils' General Committee, and of the State and Municipal Section; John C. Hoyt, Chairman of the Federal

Section; and Francis L. Stuart, Chairman of the Railroad Section.

A general discussion of this timely question is invited, and all engineers will be welcome at the meeting.

MEETING OF RADIO ENGINEERS

The next meeting of The Institute of Radio Engineers will take place on the evening of Wednesday, November 5th, 1919, at 8:15 p. m. at the Engineering Societies Building, 29 West 39th Street, New York City.

A paper on "Static Elimination by Directional Reception" will be presented by Mr. Greenleaf W. Pickard. There will be presented, with illustrations, an account of extensive researches over a period of years, dealing with the reduction of atmospheric disturbances in radio reception.

Institute members and their friends are cordially invited to attend.

NATIONAL DRAINAGE CONGRESS

The National Drainage Congress will have its Eighth Annual Meeting at the Planters Hotel, St. Louis, Mo., November 11th, 12th and 13th, 1919.

The Congress is concerned with the development of the natural resources of our country and the protection of the public health by preventing and remedying such unfortunate conditions as may be caused by the existence of swamp lands and as may follow the floods of our rivers.

An invitation to attend this Congress and take part in its deliberations is extended to Institute members.

JOINT MEETING IN NEW YORK, OCTOBER 1, 1919

A joint meeting of the A. I. E. E. and the Institute of Radio Engineers was held in the Auditorium of the Engineering Societies Building in New York, October 1, 1919.

The meeting was called to order by President Townley of the A. I. E. E., who, after a few introductory remarks, presented Mr. E. F. W. Alexanderson of the General Electric Company. Mr. Alexanderson presented the first paper of the evening entitled "Transatlantic Radio Communication", after which Vice-President Hogan of the I. R. E. introduced Mr. J. H. Dellinger of the Bureau of Standards who abstracted his paper on "Principles of Radio Transmission and Reception with Antenna and Coil Aerials". The final paper of the evening entitled "Telephone Repeaters" by B. Gherardi of the American Telephone and Telegraph Company and F. B. Jewett of the Western Electric Company, was presented in abstract by Mr. Gherardi.

President Townley then announced that General Edward Russell, chief in command of the Signal Forces of the United States in the American Expeditionary Forces was present and called upon General Russell to address the meeting. General Russell responded in a brief address in which he paid a high tribute to the engineers of the Signal Corps for their very notable work during the war. Owing to the lateness of the hour there was no discussion of the papers but President Townley announced that the Institute of Radio Engineers would hold a meeting at a later date at which time opportunity would be afforded for a full discussion of both of the radio papers.

MEETING IN PHILADELPHIA, OCTOBER 10, 1919

A joint meeting of the American Institute of Electrical Engineers and the American Physical Society, to which members of the Franklin Institute were also invited, was held in Philadelphia at the Bellevue-Stratford Hotel, October 10th and 11th, 1919. About 350 members and guests registered.

The meeting opened Friday morning with a session of the American Physical Society, the first paper being "The Present Theories of Atomic Structure" by Saul Dushman. Paper was illustrated by mechanical models of the structure of atoms. The next paper was "Special Applications of the Octet Theory" by Irving Langmuir, which was followed by a paper on "Spectroscopic Evidence Regarding Atomic Structure" by F. A. Saunders. The fourth paper of the session was entitled "Bearings of High Pressure Phenomena on the Problem of the Constitution of Matter" by P. W. Bridgeman.

Following the morning session a complimentary luncheon was tendered by the Philadelphia Section to the Board of Directors and Committeemen of the Institute.

The afternoon session on Friday was held under the auspices of the A.I.E.E. and four papers were presented. The first paper was by Dr. A. W. Hull of the General Electric Company, entitled *The Arrangement of Atoms in Metals*; this was illustrated by models. The next paper *The Oscillating Vacuum Tube as a Generator of Electric Power* by J. H. Morecroft and H. T. Friis, of Columbia University, was presented by Prof. Morecroft and illustrated by lantern slides of oscillograph records. The third paper was by Dr. S. J. Barnett of the Carnegie Institute of Washington, entitled *Electromagnetic Induction.* The fourth paper on *The Piezo Electric Effect* by A. M. Nicolson of the Western Electric Company, was abstracted by the author and was accompanied by demonstrations.

Friday evening an informal dinner was held in the Stratford Room of the hotel and was attended by 215 members and guests. Following the dinner brief remarks were made by presidents of both the participating societies.

On Friday evening there was a joint session of the A. I. E. E. and A. P. S. at which two papers were presented. The first by H. A. Bumstead of Yale University on *The Indispensibility to each Other of Pure and Applied Science*; the other by J. J. Carty, vice-president of the American Telephone and Telegraph Co. on *Pure Science and Industrial Research.* These papers elicited quite a spirited discussion in regard to research work and especially upon the methods practised in the universities and technical schools for producing competent research workers.

The sessions on Saturday were both under the auspices of the Physical Society and were held at the plant of the Leeds and Northrup Company at Germantown, to which those in attendance were transported by automobiles. The morning session was called for 9:30 a.m. and the first paper was presented by Mr. M. E. Leeds of the Leeds and Northrup Company and was entitled *Research Development and Technical Control in a Small Industry.* This was followed by a paper on *Some Research and Development Problems of the Leeds and Northrup Company* by R. B. Smith of that company. Following the presentation of these papers the members were conducted by guides on an inspection trip through the company's plant after which the members assembled in the meeting room where a complimentary buffet luncheon was served by the Leeds and Northrup Company. After luncheon the meeting again convened, and a number of short papers were presented under the auspices of the A.P.S. the titles being as follows:

"A Precision Potentiometer," by Arthur W. Gray; "On Establishing of the Absolute Temperature Scale," by Frederick G. Keyes; "The Crystal Structure of Ferro-Magnetic Metals," by Albert W. Hull; "Hydrogen Overvoltage," by D. A. MacInnes, Leon Adler and A. W. Contieri; "Note on a Method of Measuring the Decrease of Electron in Thin Films by Means of Characteristic X-Rays," by Bargen Davis; "The Application of Motion Picture Photography to Ballistics and Airplane Performances," by F. C. Brown; "Unipolar Induction," by W. F. G. Swann; "Magnetic Resistance Effects in Films of Bismuth," by F. K. Richtmyer and L. F. Curtiss; "The Spectral Photoelectric Sensitivity of Molybdenite as a Function of the Applied Voltage," by W. W. Coblentz and H. Kahler; "Ionization and Resonance Potentials for

Electrons in Vapors of Lead and Cadimum," by F. L. Mohler, Paul D. Foote and H. F. Stimson; "The Calculation of Audion Constants," by R. W. King.

A. I. E. E. DIRECTORS' MEETING OCTOBER 10, 1919

The regular monthly meeting of the Board of Directors of the Institute was held at the Bellevue-Stratford Hotel, Philadelphia, on Friday, October 10, 1919, at 10:30 a. m.

There were present: President Calvert Townley, New York; Vice-Presidents C. E. Skinner, Pittsburgh, and N. A. Carle, Newark, N. J.; Managers Charles S. Ruffner, Wm. A. Del Mar, Walter I. Slichter, New York, Charles Robbins, Wilfred Sykes, Frank D. Newbury, Pittsburgh, E. H. Martindale, Cleveland, Walter A. Hall, West Lynn, Mass., and L. E. Imlay, Niagara Falls, N. Y.; Treasurer George A. Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

A report was presented of a meeting of the Board of Examiners held on September 29, 1919; upon the recommendation of the Board, the following action was taken on pending applications: 21 Students were ordered enrolled; 148 applicants were elected to the grade of Associate; 6 applicants were elected to the grade of Member; 13 applicants were transferred to the grade of Member; 4 applicants were transferred to the grade of Fellow.

Chairman Slichter of the Meetings and Papers Committee reported orally regarding tentative plans for Institute meetings as announced elsewhere in this issue.

Upon the recommendation of the Finance Committee, monthly bills amounting to $17,590.99 were approved.

Upon the recommendation of the Finance Committee, a tentative budget covering the activities of the Institute for the year beginning October 1, 1919, was approved.

In addition to the above, many other matters relating to important activities and the general policy of the Institute were discussed and in most cases were referred to various committees and officers for further consideration. Reference to these matters may be found in this and future issues of the PROCEEDINGS under suitable headings.

METHOD OF FINANCING SECTIONS

Resolutions Adopted by Board of Directors of A. I. E. E. October 10, 1919

WHEREAS, the present practise in financing the activities of Institute Sections frequently involves payment of bills from the personal funds of Section officers, who are later reimbursed by Institute headquarters; and

WHEREAS, it is desirable that Institute funds be made available for prompt payment of the expenses incurred locally by each Section.

RESOLVED, that the secretary of each Section, or other officer as designated by the Executive Committee of the Section, open a bank account in his capacity as an officer of the Section and deposit therein the funds received from Institute headquarters as indicated below, and any other funds of the Section received from other sources; and that payment of the expenses of the Section be made from this account.

RESOLVED, further that the Treasurer and the Secretary of the Institute be authorized to make a remittance in October of each year to each Section, of an amount equivalent to one-half the maximum amount to which the Section would be entitled under the By-Laws for the year's work, less any unexpended balance of the funds provided by the Institute during the preceding year; and that an accounting be made to the Finance Committee of the Institute, through the Secretary, at the end of six months, or earlier if necessary, whereupon a remittance of the second half of the maximum amount available will be similarly remitted to the Section and similarly accounted for during the month of September each year.

Any unexpended balance available at the end of the year shall be considered as reverting to the Institute treasury, but for convenience will remain in the local bank account and be deducted from the sum remitted in October from Institute headquarters; *i. e.*, unexpended balances shall not be added to the following year's appropriation.

PAST SECTION MEETINGS

Detroit—Ann Arbor.—October 10, 1919, Board of Commerce, Paper: "Development of Automobile Starters" by C. E. Wilson.

Lynn.—October 8, 1919, G. E. Hall. Subject: Transportation. Speakers: Mayor W. H. Creamer, Messrs. Ralph S. Bauer and Fred. A. Cummings. Attendance 200.

Milwaukee.—October 15, 1919, Athletic Club. Illustrated address by Professor Max Mason of University of Wisconsin. Attendance 150.

Portland.—October 7, 1919, Gasco Building. Paper: "Changing 33-Cycle Apparatus to Operate on 60-Cycle Circuits" by D. W. Proebstel and E. H. LeTourneau. Attendance 75.

Rochester.—Election of officers as follows—chairman, J. W. Morrison; secretary, H. J. Schiefer; executive committee, Ray H. Manson, O. W. Bodler, F. C. Taylor, C. T. Wallis, and E. D. Smith.

Seattle.—September 16, 1919, Butler Hotel Cafe. Annual dinner, followed by general business meeting.

St. Louis.—September 24, 1919, Engineers Club. Address by President Calvert Townley on Institute Affairs and the work of the Development Committee. Joint meeting with the Associated Engineering Societies. Attendance 124.

PAST BRANCH MEETINGS

University of California.—September 24, 1919, Mechanics Building. Address by Mr. W. C. Pomeroy on "History and Aims of the A.I.E.E."

Clemson Agricultural College.—October 14, 1919. Address by Prof. M. T. Burch on "Electrical Equipment of Sea Planes." Current Engineering News by J. M. Black. Election of officers as follows—chairman, J. B. Fitzgerald; secretary, J. F. McHugh; treasurer, R. R. Shedd. Attendance 75.

Kansas State Agricultural College—October 2, 1919. Papers; (1) "Automobile Transmission" by R. S. Knox; (2) "Sub-Station at Camp Funston" by R. A. Graves; (3) "Frequencies" by M. J. Lucas.

University of Maine.—October 15, 1919, Lord Hall. Election of officers as follows—president, Samuel E. Jones; vice-president, Frederick C. Bisbee; secretary, Wesley C. Plumer; treasurer, Henry Butler; executive committee, Professor Barrows, Lloyd R. Douglass and Henry Howard. Attendance 26.

Massachusetts Institute of Technology.—October 15, 1919. Short addresses by members of faculty and students. Attendance 65.

Michigan Agricultural College.—October 9, 1919. Illustrated address by Mr. P. G. Andres on "Power Transmission through Various Media." Attendance 79.

Missouri.—September 15, 1919, Engineering Building. Relation of A.I.E.E to the Student by A. C. Lanier; Summer Experiences, by E. M. Kerr, Ben Fleshman and B. J. George. Election of officers as follows—secretary, F. H. Miller; to executive board, C. H. Albus and A. C. Bruner. Attendance 48.

September 26, 1919, Engineering Building. Paper: "The Field of the Commercial Engineer" by R. H. McLain. Attendance 35.

Ohio Northern University.—September 25, 1919, Dukes Memorial. Addresses as follows—(1) "The Work and Benefits of the A.I.E.E." by Prof. M. B. Jepson; (2) "Why Every Electrical Student Should Belong to the A.I.E.E." by Prof. F. F. Turner. Attendance 20.

October 1, 1919, Dukes Memorial. Papers: (1) "A Proposed 220,000 Volt

Transmission Bus" by Carl Selpein; (2) "The Commonwealth Edison Company's Student Course" by J. E. Wells. Attendance 32.

October 15, 1919, Dukes Memorial. Oscillograph Demonstration by Prof. F. F. Turner. Remarks by engineers from A. T. & T. Co. Attendance 40.

Purdue University.—September 16, 1919, Electrical Building. Addresses as follows—(1) "The National A.I.E.E. and Its Work" by Prof. C. F. Harding; (2) "The Local Branch of the A.I.E.E. and the Benefits of being a Member" by Prof. A. N. Topping. Attendance 200.

September 30, 1919, Electrical Building. Paper: "The Keokuk Power Plant" by A. R. Kaufman. Report of National Convention of A.I.E.E. at Lake Placid by C. O. Wood. Attendance 70.

Rose Polytechnic Institute.—October 13, 1919. Business meeting. Election of officers as follows—chairman, Frank M. Stone; secretary, Harold L. Kessler.

Rensselaer Polytechnic Institute.—September 24, 1919, Sage Laboratory. Addresses on " The R. O. T. C. Training" by Lieut. Col. Putney and member of the faculty. Attendance 105.

Syracuse University.—October 9, 1919, College of Applied Science. Paper: "Comparison of Electric and Steam Locomotives and Their Operation" by H. D. Kelsey. Election of officers as follows—chairman, Gerard W. Terry; secretary, Maurice D. Low. Attendance 15.

A. & M. College of Texas. October 6, 1919, Electrical Engineering Building. Election of officers as follows—chairman, L. E. Cook; treasurer, H. M. Allen; secretary, D. D. Murphree. Attendance 78.

Virginia Polytechnic Institute.—October 7, 1919. Election of officers as follows—president, L. D. Fry; secretary-treasurer, R. W. Harney. Attendance 24.

University of Washington.—October 7, 1919, Forestry Hall. Paper: "Some Aspects of Electrical Engineering" by L. F. Burtis. Election of officers as follows—chairman, George R. Rice; secretary, McKinley Donovan. Attendance 28.

I. E. C. MEETING, LONDON, OCTOBER 20-24

A plenary session of the International Electrotechnical Commission was held in London, October 20-24, 1919. This meeting marked the resumption by the I. E. C. of activities discontinued because of the war. The U. S. National Committee was represented at this session by Dr. C. O. Mailloux, H. M. Hobart, L. W. Chubb and James Burke who sailed from this country on October 8th. A report of the session will appear in a future issue of the PROCEEDINGS.

THE VAIL LIBRARY AT M. I. T.

The attention of Institute members is called to the existence of a very interesting and comprehensive library on electricity and electrical engineering, the Vail Library, at M. I. T.

This library was collected in England by Mr. Dering, and comprises about 20,000 volumes. Many early and rare books are included such as Gilbert's "De Magnete," 1500 (first edition), Cabeo's Philosophis Magnetica," 1629, etc. In addition to the books on electricity, there is a very interesting collection on early development in aviation.

In 1912, President Theodore N. Vail of the A. T. & T. Co. purchased the library and presented it to M. I. T. Since its receipt the collection has been cataloged and about 1000 new books added. This collection offers a wide and interesting field for research and study.

ENGINEERING COUNCIL

CLASSIFICATION AND COMPENSATION OF ENGINEERS

Engineering Council's Committee on the Classification and Compensation of Engineers is continuing its work and getting results. Its three sections, on Railroads, Federal Government, and State and Municipal Governments, are all active. Under a recent date the State and Municipal Section reports that forty-five responses have already been received to its questionaires sent out a few weeks ago. The following notes are supplied by the Chairman of the committee, Mr. Arthur S. Tuttle, Member, American Society of Civil Engineers, and Deputy Chief Engineer, Board of Estimate and Apportionment of the City of New York.

In the case of 8 services the morale is reported to be good but in most of these it appears that the organization reported is a new one or that radical changes in compensation have recently been effected. In 20 reports no comment is made as to the present morale while in 17 instances the general conditions are said to be as follows:

"Morale would be improved if adequate salaries were allowed."

"Practically all men are clamoring for more pay, but as our budget was fixed while the country was at war we are unable to secure the additional funds necessary to raise salaries further."

"Impossible to hold first class men at these rates. Morale is generally good."

"All want more money. Dissatisfied on account of low pay."

"Our organization is in a condition of unrest and change owing to small appropriation."

"Loyal enough generally, but dissatisfied with pay, and accept better offers readily. Difficult to fill their places at same rates."

"Excellent, but all employees desire increase in compensation over that already granted. New men cannot be obtained at previous salaries."

"Dissatisfied with present compensation."

"Force depleted. Employees leaving to take positions at greater compensation. Men remaining uneasy and dissatisfied."

"I might say that I thoroughly agree with the men in New York City who demand a flat raise of $500. yearly in all classes of the service."

"There is a decided spirit of unrest and dissatisfaction due to the fact that engineering salaries have not been increased in proportion to the advance in the cost of living, and to salaries and wages paid to non-professional men and skilled labor."

"Rate of pay tends to drive more active and self-reliant younger men out of this service—lowering general average."

"Majority of men feel they are underpaid."

"Lack of consideration for services rendered has discouraged the force."

"A general increase of $150. to $400, effective September 16, 1919, has improved the morale of the force, which was affected both by a general reduction of force and the economic situation."

"Increasing restlessness on the part of the entire force due to lack of proper salary increases to meet growing expenses."

"While men for the most part do their work satisfactorily, there is a general feeling of unrest and discouragement as the result of what they consider failure to recognize their efforts."

THE BOSTON-WASHINGTON SUPER-POWER LINE

Engineering Council Endorses Proposed Legislation

The Fuel Conservation Committee of Engineering Council recently presented a report upon the bill before Congress which provides for a survey and report on the economic production and distribution of energy in the Boston-Washington coast region.

Prof. L. P. Breckenridge, Chairman of the Committee, states that the time has now come when Engineering Council may well take some helpful action in connection with the above subject, as there seems every reason to believe that the principles involved will result in a large conservation of coal in connection with the development of industrial power. The report is accompanied by extracts from an address by Mr. W. S. Murray before the Bridgeport Chamber of Commerce on September 10th which heartily endorses the project. He states that "by far the most important consideration now is the investigation which Secretary Lane has proposed to Congress by which will be determined the amount and location of waste in this Northeast Atlantic Seaboard Zone, and in the report to be written under the auspices of the Department of the Interior there will be developed engineering and construction plans necessary to its saving. It is my belief that if by this investigation it is proved beyond peradventure of doubt that in the zone described there is going to waste $300,000,000 a year, and a perfectly practical plan is ready at our hands, by which its saving can be effected, there will be no question as to whether it can be financed, but rather what will be the best method of finance to pursue."

Mr. Calvert Townley, Chairman of the Water Conservation Committee of Engineering Council reports favorably in regard to the proposed legislation, saying, "I regard this investigation as very much worth while. Mr. W. S. Murray, for many years a prominent consulting electrical engineer in New England and who has specialized in problems of transportation as well as of power generation and distribution, has made a rough preliminary canvass of the situation and advises me that the possible saving if all power could be supplied by the utilization of the available water power and the construction of very large and efficient steam plant would be of the order of magnitude of $300,000,000."

In view of these reports Engineering Council at its meeting of October 16th took the following action:

"The Fuel Conservation Committee having recommended to Engineering Council that Council support legislation to provide an appropriation to enable the United States Geological Survey to investigate "the possible economy of fuel, labor and materials resulting from the use in the Boston-Washington Industrial Region of a comprehensive system for the generation and distribution of electricity to transportation lines and industries"; and

Engineering Council appreciating the importance of conserving our national fuel resources, of equalizing the cost of power and of relieving railroad congestion, and

Engineering Council believing that the density of traffic and of industrial consumption of power in the territory adjacent to the north-eastern Atlantic seaboard is sufficient to justify physical and economic relief by the application of the principles inherent in super-power generation and distribution, be it

RESOLVED, that Engineering Council endorses legislation making a suitable appropriation for the proposed investigation as a measure conducive to the national welfare.

UTILIZATION OF CULM

The Fuel Conservation Committee of Engineering Council has called attention to the great need of fuel conservation if the anticipated strike in the bituminous coal field comes off on November 1st as now seems probable. Attention is called to the fact that there is in the anthracite region millions of tons of culm that can be used in the generation of steam at properly equipped boiler plants and the power transmitted to New York, Philadelphia and vicinity by means of electrical transmission.

In the utilization of this culm, experiments have shown the economic value of No. 4 Buck which is coal passing through a 1/16 in. mesh and over a 1/32 in. mesh, and have gone further in the utilization of the finer culm passing through a 1/32 in. mesh and pulverizing it until it will pass through a 300 mesh and burning it under boilers. Two plants of this kind are now in operation in the anthracite region and are quite successful.

Another rather interesting experiment was a mixture of 30 per cent of this pulverized coal with 70 per cent of oil and using that in the generation of steam in the place of pure oil. This utilization of the fine anthracite, which has always been a waste product and thrown away, is not only fuel conservation in its truer sense but also, at this time of a threatened bituminous strike when no strike is contemplated in the anthracite field, would furnish fuel to manufacturing plants that otherwise would be obliged to shut down.

ENGINEERS IN THE 1920 UNITED STATES CENSUS

As a result of Engineering Council's request to the Director of the Census, the National Service Committee has been successful in effecting a reclassification of Engineers so that all technical engineers will be listed as such, separately and distinctly from the non-technical engineers. Thus, the next census will bring an enumeration of all technical engineers together as one unit under the main headings of Civil, Mechanical, Electrical and Mining. Architects will also be enumerated separately.

This will enable the engineering profession, the Government or any other interested organization or person to know exactly how many technical men there are in the United States and in each state. Under separate headings the enumeration will also include non-technical engineers, (stationary engineers, locomotive drivers, and other engine-men); but there will be no group heading for the latter.

It is believed that every professional engineer can, with very little violence to the facts, place himself in one of the broad classes adopted for the 1920 Census: Civil, Mechanical, Electrical, Mining. With the general cooperation of all Engineers along these lines a much better enumeration should result than in any preceding census.

ENGINEERING COUNCIL JOINS NATIONAL CHAMBER OF COMMERCE

Engineering Council has been elected to membership in the Chamber of Commerce of the United States. In joining this great association of trade and commercial organizations Engineering Council adds its strength to organized business and gives its members an opportunity to register their views with the central body in the consideration of national questions that affect business.

The Chamber of Commerce of the United States was formed in 1912 as a means of bringing together all of the industrial and business elements of the country. How well it has succeeded is shown in a recent statement that the membership of the Chamber now consists of more than 1100 organizations in every state of the union, in the outlying possessions and of all the principal American chambers of commerce abroad.

One of the chief aims of the National Chamber is to obtain the best business thought on national questions that concern business. This is done through a system of referenda on which the more than half a million individual members of the organizations comprising the Chamber are entitled to vote through their associations. The opinion of business, thus obtained, is transmitted to Congress and to public officials and is given to the public.

The National Chamber will be able to render assistance to Engineering Council in many ways. It will receive weekly a general bulletin containing the freshest and most authentic news of what is transpiring at Washington, the city to which all business is looking these days. In addition there is a special legislative bulletin issued weekly while Congress is in session following the progress of all legislation concerning business. Special bulletins are issued also as occasion arises.

REPORT OF CONFERENCE OF FEDERAL MAP-MAKING ORGANIZATIONS

Following the suggestion of Engineering Council and at the direction of the President, representatives from each of the Federal Government bureaus interested in map making were called into a conference for the purpose of coordinating all of the Government's map-making activities. This conference has now reported back to the President the results of their findings, which indicate that Engineering Council's recommendation in this matter was well founded. Shortly after the conference went in session the following engineering and scientific societies were invited to send representatives to the conference meetings. Owing to lack of time, however, it was agreed that these organizations would present their recommendations to the permanent conference to be organized. Engineering Council, the Ameri-Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Mechanical Engineers, the American Institute of Electrical Engineers, the American Association of State Geologists, the American Association of State Highway Officials, the National Research Council the National Geographic Society, the Association of American Geographers, the American Geographical Society and the Geological Society of America.

While the conference report states that its members were of the opinion that little duplication of effort existed, it goes on to recommend the formation of a permanent Board of Surveys and Maps. An extended review of the map-making activities which is given as an appendix to the report indicates that this recommendation is a logical step. The conference recommendations concerning this Board of Surveys and Maps are as follows:—(1) the Board is to be composed of representatives of mapping bureaus to be assisted by outside engineering organizations, which have been named above; (2) the establishment of an information office in one of the Government bureaus, preferably the Geological Survey, which is to be under supervision of the Board and is to be a mapping information clearing house for the Government and outside engineering organizations; (3) copyright laws are to be so changed that copies of all maps made in the United States and with Government authority, will go to the central information office; (4) the Government departments to receive orders to cooperate with the Board; (5) future topographic maps of all kinds are to conform with specifications for the standard topographic map; (6) he U. S. Coast and Geodetic Survey to have supervision of final adjustment of all important control data under specifications approved by Board of Surveys and Maps; (7) Surveys in the form of maps and publications are to be issued as soon as possible after field work has been completed; (8) program of the Interdepartmental Committee on Aerial Surveying was approved.

Outside technical and scientific organizations that are called in for consultation are to operate in an advisory capacity only, responsibility for action on

Governmental work is to rest solely with the Governmental agencies.

NOTES FROM THE NATIONAL SERVICE COMMITTEE*

International Communication

Because of the international difficulties that have arisen and the many different angles from which international communication has been approached, it has been recommended that the President of the United States arrange in his discretion, an international conference to assemble in Washington to consider all international aspects of communication by telegraph, telephone, cable, wireless telephone and wireless telegraphy. Representatives of this country are to be appointed by the President and are to make recommendations with a view to providing the entire world with adequate facilities for international communication on a fair and equitable basis.

If the bill proposing this conference is enacted, $75,000 will be appropriated for expenses incidental to the conference and its report.

Machine Tools for Technical Institutions

Recently, the House passed a bill authorizing the Secretary of War to sell to schools, universities and colleges surplus machine tools which could be used for educational purposes. The educational institutions were to be charged 10 per cent of the original cost of these tools.

The Senate Committee on Military Affairs has now reported another bill authorizing the Secretary of War to transfer permanently to the Federal Board for Vocational Education, about $250,000 worth of this equipment. Surplus machine tools are to be loaned to the Board, which in turn, distributes them to schools and colleges throughout the country. This bill proposes to place the title to these machines in the hands of the Vocational Board, which is to report to Congress annually as to the disposition and use of the tools.

Steel Basing Point

The Federal Trade Commission has made public the results to date of the controversy over the single and plural basing for steel throughout the United States. Five of the great steel consuming interests have asked the Federal Trade Commission to assume jurisdiction and declare the present system in violation of the Clayton anti-trust law. Forty-three interests have submitted statements opposing abolition of the present system and thirty-six favor a change.

According to Government specialists, who have covered this subejct, a great deal of useless agitation with no prospect of benefiting the great body of consumers, is going to result from the proposal. They say it must be recognized that the raw materials used in the making of steel can be assembled cheaper at Pittsburgh than at any other point and a change would involve making over the whole economic structure under which the steel industry operates. The greatest law-suit in the history of the country is predicted by Judge Gary, should an effort be made to put plural basing points into effect.

Commercial Testing at Government Arsenals

The development of the plan to conduct tests of materials for industrial purposes at Government arsenals has shown considerable progress during the past fiscal year. At Watertown Arsenal for instance, development work has been carried out not only along metallurgical lines but in all phases of work, including the development of cutting oils and the examination of quenching media. During the fiscal year this arsenal has tested 43,964 specimens. This is an increase of 259 per cent over the work of the preceding year. The total number of chemical analyses for the fiscal year was

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*Contributed from the Washington office of the National Service Committee, Engineering Council.

48,339. This is an increase of 522 per cent.

This is an indication of the increased attention that industrial firms are giving to exact physical and chemical tests of material entering into their product. It is also one of the best indications that the war has affected the use of standardization and more exacting specifications.

Water Power

Engineering Council through its Water Conservation Committee is making determined efforts to assist in passing a bil (H.R.3184) which will give the country good water power legislation. The importance of this bil' has been stressed with senators individually and a special effort has been made through the engineers of Wisconsin to bring the senators from that state into line,—they lead the opposition to previous water-power bills and are planning to do the same with this bill. The interest shown by requests for exact information on the water-power bill to the National Service Committee of Engineering Council indicates that the active interest and support required will be given this bill by engineers.

The bill as reported to the Senate contains several important changes in the text of the bill passed by the House but these are not fundamental changes, and it is contemplated that the House will concur. The Senate Committee has explained and clarified the definitions of "reservations", "navigable waters" and "costs." A proportionate license fee not exceeding twenty-five cents per horse power is proposed, which is to defray costs of the administration of the act. Fair rentals are to be charged for Government dams and other Government property on water-power sites. The House bill gave the Commission unlimited power to fix annual charges whereas the Senate amendment limits this blanket power as indicated above. A change was made to provide that in case the United States does not exercise the right to take over the works the license tendered shall be "on reasonable terms" and "which is accepted" by the original or the new license. That provision was thought necessary to make it certain that capital would invest under the law. A provision for severance damages was stricken out by the sub-committee and was restored by the full committee, so that it now appears in the bill.

Delay faces the action on this bill because past efforts to have immediate consideration indicate that it must await the disposal of the Peace Treaty before it comes up for consideration on the Senate floor.

Engineering Council's Hearing before National Budget Committee

At the request of the chairman of the Select Committee on the Budget, representatives of Engineering Council expressed the opinion of engineers on the subject of a National Budget System, on October 1st. The invitation was received through the National Service Committee of Engineering Council and its chairman, Mr. M. O. Leighton, introduced Council's representatives to the Committee. Mr. Charles Whiting Baker, the chairman of Council's Public Affairs Committee, gave reasons for the general desire among engineers for the adoption of a budget system in the handling of national revenue. He brought out the fact that an important part of Government work is of an engineering nature, which is not being handled with a maximum of efficiency under the present system of appropriating funds because insufficient financial power is left to discretion of the director of the work.

Mr. Nelson P. Lewis, Chief Engineer, Board of Estimate and Apportionment, New York City, explained in considerable detail the efficiencies and economies which have resulted from the operation of the budget system in New York. He showed that under existing conditions it would practically be impossible for New York to get along under any other system and declared that the budget had made an orderliness of administration which could not have been otherwise obtained.

Director and Chief Engineer of United States Reclamation Service, Mr. A. P. Davis, pointed out the necessity of the proper segregation of Government bureaus before an effective budget system can be adopted. As a correct example of segregation, Mr. Davis cited the plan proposed in the Jones-Reavis bill, whereby all related bureaus having engineering activities would be placed in the same department. Such a plan would simplify and make possible the efficient use of the budget system and of lump sum appropriation where responsible department heads could be obtained.

Mr. W. R. Warner of the Warner-Swasey Company, Cleveland, pointed out the great advantages that had accrued to private engineering operations through the use of the budget systems.

It was pointed out during the hearing that engineering work was particularly hampered by the present system of appropriation. The lump sum on "continuing contract" method was held to be necessary in many cases. Illustrations of the success of the plan are the Panama Canal, levee work being done on the Mississippi River and the large reclamation projects.

Petroleum Research Work

The plan recently started for the organization of a Division of Research and Statistics in the American Petroleum Institute will probably shortly be consummated. It is proposed to expend $500,000 annually for this research work. The organizations work as now outlined provides for a Technical Director, who is to be in general charge of all the work. He is to be assisted by Consulting Technical Experts who are to be distinguished specialists in the industry and who are to serve without pay. In addition there is to be an advisory committee made up of one representative from the Bureau of Standards, Bureau of Mines, Geological Survey, Society of Automotive Engineers, National Automobile Chamber of Commerce, American Institute of Mining Engineers, American Society for Testing Materials, American Chemical Society, and the National Research Council. This committee is to meet regularly to discuss the problems of the petroleum industry. An engineer and chief economist are to come under the Director. The economist is to be in charge of statistics, economic phases of the industry and publicity. It is the intention to centralize in the institute all figures that may be required by the states or Federal Government, which would be of value to members of the Institute. They include price figures for crude oil, refined products and natural gas.

The engineer of the division is to coordinate the research work to be undertaken by the sub-division of production, chemical engineering, utilization and special research. Systematic study is to be made of the questions of leasing and bonuses, drilling, pipe lines, storage and tank cars. Many new uses for petroleum products, patents and other special problems are to be studied.

The economist will study international policies affecting the petroleum industry and for this purpose agents are to be stationed in important foreign commercial centers. Uniform cost of accounting and uniform laws and regulations are to be sought.

The policy of the American Petroleum Institute, it is announced, will be to employ the highest type of men and pay them proportionate salaries.

NATIONAL SAFETY COUNCIL

The Eighth Annual Safety Congress of the National Safety Council was held at Cleveland October 1 to 4th, 1919. Among the many papers of interest presented were the following: Effective Means of Focusing the Responsibility for the Prevention of Accidents upon Foremen, J. W. Easley Kansas City Telephone Co., Working Safely on Live High-Tension Lines, H. J. Burton, Consumer's Power Co.; Tagging, Barriers, Markings and Practises of Operators, W. C. Wagner, Phila. Electric Co.; Spasmodic Safety Efforts and the Harmful Results, H. M. Webber, Supt. Dept. of Claims, Chicago Telephone Co.

AIRPLANE ANTENNA CONSTANTS

The Bureau of Standards has just issued a scientific paper entitled "Airplane Antenna Constants, which contains the results of experimental work on various types of airplane antennas. The paper gives methods of measuring the capacity, inductance, resistance and natural wave length, and the directional transmitting effect of airplane antennas with the plane in flight are described. Using these methods the results obtained upon various forms of fixed antennas, as well as one, two and four trailing wires, are recorded. Copies of the paper may be obtained by addressing a request to the Bureau of Standards.

MOTOR TRANSPORT TRAINING SCHOOLS OF THE ARMY

The United States Army is definitely launched in the field of vocational training for the motor transport corps. It has no option in the matter, for men skilled in automobile vehicle operation and repair do not exist in anything like adequate numbers for the requirements even of civil life; and the war with Germany has demonstrated that no matter how good our Army may be in other respects, its efficiency will be conditioned by that of the motor transport branch.

Therefore, the Army is organizing schools to train men in the various branches of automobile repair, construction, and operation. They are real schools under trained teachers where the time of the pupil is wholly devoted to receiving instruction.

Apart from the military necessity, the automotive industries will benefit by the establishment of this training system.

The United States Civil Service Commission is receiving applications to fill 150 positions of assistant instructor in motor transport training schools. The entrance salaries range from $1,800 to $2,400 a year. Detailed information may be obtained from the U. S. Civil Service Commission, Washington, D. C. or from the secretary of the U. S. Civil Service Board at the post office or custom house in any city.

INDUSTRIAL RELATIONS

There has recently been established an organization for the specific purpose of getting the labor facts in every line of industry in this country and abroad; analyzing, digesting and sending them in weekly bulletin form for the use of executives. This service examines each week a large number of labor publications; industrial pronouncements from every labor group; public, semi-public and local documents; books and articles dealing with labor problems and investigates projects undertaken by employers in the field of industrial relations. The service digests and summarizes but does not deal in opinion.

Members of the Institute interested in industrial relations should communicate with Meyer Bloomfield, 6 Beacon Street, Boston, Mass.

ENGINEERING SERVICE BULLETIN

Opportunities.—The Institute, is particularly anxious to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in this BULLETIN. The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Services Available.—Under this heading brief announcements (not more than fifty words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office files.

Note.—Copy for publication in the BULLETIN should reach the Secretary's office not later than the 20th of the month if publication in the following issue is desired.

All replies to either "Opportunities" or "Services Available" announcements should be addressed to the number indicated in each case, and mailed to Institute headquarters.

Engineering Societies Employment Bureau.—This is a joint bureau under the auspices of the Engineering Council. The Institute's employment service is coordinated with that of the joint bureau.

OPPORTUNITIES FOR SERVICE

V-537. Foreman wanted for electrical instrument and testing department. Applicant should have had executive, practical and technical experience. This position is open only to a man who appreciates the value and necessity of maintaining and improving the quality of the products. In reply state age, experience and compensation desired.

V-569. Draftsmen and designers wanted by prominent manufacturing concern located in middle West. Men familiar with the design of electrical apparatus and with considerable mechanical experience preferred. Splendid opportunity for men released from Army or Navy who have not as yet found permanent positions. In reply please cover the following information: education, experience, age, and salary expected.

V-576. Load Dispatcher for a large combined steam and hydroelectric system. To deal more with the economical side of load dispatching rather than operation. Must have operating experience. Engineering graduate preferred. Location Eastern city. Salary about $175.

V-578. Recent graduate with thorough technical knowledge for general electrical engineering with large central station company in New York City.

V-582. Mechanical Designers for special work. Men who have had experience in the designing of small movement work and fine mechanical apparatus preferred. In reply give age, experience and references.

V-585. Public Utility corporation, location New York State, has openings for two high grade recent technical graduates in its industrial sales department, preferably men who have graduated within the past two years. The work primarily that of a power sales engineer, wherein the individual must make his own complete engineering tests, reports, lighting, motor and equipment layouts, etc. The work also consists of the application of gas to industrial processes, and the supply of steam to individual users. Excellent opportunity to gain a broad engineering training.

V-587. Wire Chief. Middle West telephone company requires a wire chief for maintenance and supervision of switchboard and to be responsible for outside work as well. Pay about $150 per month, depending entirely upon ability. Give particulars of experience, age, etc.

V-588. Sales Electrical Engineers. Experienced in selling electrical apparatus to industrial plants and also other engineering equipment such as engines, pumps, air compressors, condensers, etc. State age, experience and salary desired.

V-589. Electrical Draftsmen wanted who are familiar with electrical layouts for general industrial plant work and who also have a good knowledge of mechanical drafting. In replying state age, nationality, experience, education and minimum salary acceptable with chance for advancement.

V-590. Engineering, familiar with power plant economics; salary about $200 per month; location New York City. Give particulars of experience.

V-591. A large manufacturer of static transformers has an opening for a young engineer who has had some practical experience in the design of transformers or at least has had some experience in the design of alternating current apparatus. Applicants should report their experience fully and give references if possible.

V-592. High Grade Designing Engineers. Several vacancies for men familiar with centrifugal compressors, steam turbines, special or electrical machinery.

V-593. Laboratory Assistant wanted by a public utility. Location New York City. Must be capable to test and repair electrical instruments and miscellaneous devices, and assist in general development and experimental work.

V-594. Wanted: Two instructors in electrical engineering at a State College in Middle West. One or two years practical experience desirable. Salary $1800. Work begins December 30, 1919.

V-596. Electrical manufacturing company requires the services of a graduate electrical engineer with several years experience in the design of induction apparatus. Familiarity with design calculation rather than broad experience is wanted. Must be practical, but not afraid of theory. Position presents opportunity for wide range of designing ability development. Location, Chicago. Salary $3,000.

V-597. Wanted: Young technical graduate for research department of large concern manufacturing carbon brushes. Experience in brush research desirable but not necessary. Good opportunity for advancement.

R-1371. Well known electrical firm expanding its export service requires translator to re-write electro-technical English into technical Spanish, chiefly for publications to be distributed in South America. Engineer preferred. Advancement, etc. will depend on ability and expansion of the trade. State qualifications, experience and salary expected. Location, New York State.

R-1472. Electrical Engineer. A man with electrical engineering experience for a concern manufacturing steel products.

R-1634. Sales Engineer. Highest type engineer with sales ability; desirable that man have had shop experience and be between the ages of 35 and 45 years. Proposition is to sell scales. Will be given restricted territory in vicinity of New York City. Salary on commission basis

R-1698. Operating Engineer. Must have experience in sugar and power plant work, also in electrical work. Two months vacation in the States allowed with passage paid both ways. Single man furnished with board. Married man furnished with residence. Location Porto Rico. Salary $2500.

R-1706. Superintendent for power plant. Must have had experience as superintendent of power plant, to supervise operation of industrial power plant. Location, West. Salary, good for qualified man.

R-1733. Electrical Draftsmen. Must have several years experience in drafting along electrical engineering lines. Capable of working without much supervision. Location, Delaware.

R-1744. Sales Engineer. Electrical Engineer with illuminating engineering knowledge. Location, Michigan and Northern Ohio.

R-1753. Power Plant Engineer (M. E.) with electrical experience, to work up details in office and field on turbine installations, steam piping, spray pumps and cooling towers. Location, New York City.

R-1759. Sales Manager, with ability to organize a sales office to sell electric lamps; man from Atlanta district desired. Must have some experience in outside work; technical knowledge of the lamp or technical education is not essential. Opportunity will be given candidate to make himself thoroughly familiar with the lamp. Salary $150-$200 per month.

R-1770. Electrical Engineer. Native Norwegian, technical graduate, to translate Norwegian articles, specifications and correspondence into English as well as to compile from Norwegian advertisements and catalogues a directory of Norwegian manufacturers. Location, New York State. Apply by letter, stating age, education, experience and salary expected.

R-1771. Electrical Engineer. Graduate, preferably, for a position in the technical library of a large industrial firm. Good opportunity for the right man to develop a technical current news service already installed. Reading knowledge of French and German highly desirable. Apply by letter, stating education, experience and salary expected. Location, New York State.

R-1772. Writer. One of the largest industrial concerns in the country desires a man with absolute knowledge of English, and who has had electrical training or engineering experience. Location, New York State.

R-1786. Production Engineer, for large silverware manufacturer, must be technical graduate with at least five years practical experience along production lines. Must have had experience with modern methods of scheduling, planning, routing and controlling production. Give age, complete details of education and experience, and state salary expected in first letter. Location, Rhode Island.

R-1803. Salesman. Must have had experience to qualify as salesman for company selling asbestos packing and brake lining; territory will be New England and part of New York State.

R-1807. Sales Engineer, with high grade sales ability and knowledge of construction machinery, especially conveying machinery. Men who have actually handled the sales of chain shell buckets preferred, but men with experience in allied machinery and equipment will be considered. Good openings for two or three men to qualify for responsible positions.

R-1810. Sales Correspondent and Estimator. Young mechanical engineer to act as correspondent, estimator, and general office assistant; must be capable of writing effective sales letters in response to both foreign and domestic inquiries, must be able to prepare estimates and submit quotations on machinery such as we handle and must also be able to meet and interview customers who call at our office. State age, education and experience. Location, New York City.

R-1820. Sales Engineer for the Pacific Coast. Must be well informed as to power plant apparatus, well acquainted with the Pacific Coast territory and capable of handling the entire sales business on the Pacific Coast. The advertiser is a manufacturer of a well known line of power plant apparatus. This affords an excellent opening for the right man. State age, education, experience and salary expected. All communications confidential.

R-1821. Salesman, power specialties lines; technical education on steam and hydraulics; must have sales experience and be thoroughly familiar with power plant appliances, including condensers; state age and experience, together with salary expected.

R-1829. Director of Engineering, 35-45, of tactful and diplomatic personality, capable executive, qualified to direct development and experimental work, and possessed of thoroughly practical knowledge of manufacturing side of business; must have had at least ten years experience in internal combustion engine work, preferably with engines of heavy duty type. Duties would be to lay out and follow up all engineering work and take complete charge of engineering department. Location, Indiana.

R-1831. Assistant Industrial Engineer, recent graduate, preferably out of college two or three years, with some experience in industrial engineering and production, with concern manufacturing hard rubber goods, as for electrical appliances, etc.

R-1834. Efficiency Engineer, familiar with Dr. Parkhurst's methods of production. Duties will be to systematize office. Location, New Jersey. Salary $50 to $75 per week, depending on man.

R-1841. Old established concern requires factory manager thoroughly familiar with tool and machine work. Factory at present doing jobbing and contract work. Capacity of factory 200-300 men. Desire a man who can obtain 100% efficiency. State salary required.

R-1842. Assistant Sales Manager, must have had sales experience, preferably along lines of feed-water heaters, oil and steam separators, coils and bends. Location, New England.

R-1845. Designer (Electrical), must be first class man with experience on ignition systems and knowledge of gas engines; excellent opportunity in rapidly growing concern; location middle west.

R-1858. Works Manager, thoroughly experienced in light interchangeable production and assembly. Most know modern methods of control. Attractive personality, excellent record and business judgment required. Location near New York City.

R-1860. Advertising Assistant, young man, engineer, 24-28 years of age, with sufficient advertising experience and knowledge of printing and engraving to assist in preparation of technical advertising copy, letters, and circulars. To be assistant to sales manager of manufacturer of power plant equipment. Location, Philadelphia.

R-1872. Sales Engineer, graduate mechanical engineer from a representative college, of good appearance, etc. with manufacturers of special system that is applied to power and heating plants. Location Pennsylvania. Salary $175 per month; more if man's qualifications warrant it; all expenses paid, traveling east of Chicago. Openings for several men.

R-1879. Electrical Engineer. Capable of supervising and the maintenance and operating work for large pulp and paper company, which generates and is a tenant as well. Line work is single tension service (60,000 volts). Company requires enthusiastic and self-reliant man who is thoroughly competent to take over the operating end of all of the company's electrical work. Location, Quebec, Can.

R-1906. Assistant Superintendent or Works Manager, with experience in electrical and mechanical machinery; also knowledge of foundry practise. Location, vicinity of New York City.

R-1909. Electrical Engineer, with experience in automobiles, useful for exporting house in automobile department. Location, New York City.

R-1910. Assistant Engineer of Way and Structures. Technical graduate, with at least five years experience on construction work, considerable of which must have been on electric railways; must be familiar with track, paving and overhead work and competent to supervise construction and prepare estimates. Knowledge of accounting useful. Apply in own handwriting. $200-$250 per month. Location, Missouri.

R-1911. Assistant Engineer of Power. Technical graduate, construction experience and familiarity with operation and power cost accounting essential. Must be able to supervise design and construction of power house changes and additions; familiarity with steel work and piping layouts required. $200-$250 per month. Location Missouri. Apply in own handwriting.

R-1913. Assistant Engineer of Equipment. Technical graduate, must be familiar with car construction and various equipment in use on electric systems, and able to prepare specifications and supervise new car construction, conduct tests and special studies. $200-$250 per month. Location Missouri. Apply in own handwriting.

R-1926. Armature Winders; all-round men. Continuous employment for two men. $7.20 per day. Location, Baltimore.

R-1940. Technical Advertising Manager. Must have thorough knowledge of power plant practise and first-class record of past services. Unusual opportunity for able man to settle permanently in the future. State minimum salary. Location, Michigan.

R-1943. Superintendent of Power, graduate engineer, familiar with blast furnace plant, including boilers, blowing engines and turbo-generators. Must be familiar with electric line work and motor applications; salary six to seven thousand dollars. Location, Alabama.

R-1945. Electrical and Mechanical Engineers, experienced in work of designing and drafting for lock, dam and power house structures. Government work. Location, Alabama.

R-1971. Electric Sales Engineer. One with experience along technical and practical lines, competent to make layouts of factories, industrial plants and power plants and able to present the complete equipment of machinery from a sales standpoint. Location, Pacific Coast. Give details of experience.

SERVICES AVAILABLE

1446. College engineering graduate, age 25, with about two years experience in operation of power plant, design of electrical and mechanical appliances, and in switchboard development work, desires a position in medium size electrical industry where chances for advancement are good. Minimum salary $35-$45 per week, depending upon location.

1447. Chief Electrician, experienced on modern a-c. central and substation construction and operation and industrial plant work. Five years with present employers. Age 32. Location preferred—Philadelphia or South.

1448. Sales Engineer. Electrical Engineer, university graduate, available for representation at home or abroad. Six years broad experience, sales, testing, invention, development, maintenance and power plant work.

1449. Storage Battery Engineer. Ten years experience in electrical field; at present Lieut., U. S. N. Past three years in charge of installation, operation and maintenance of large storage battery and power installations in U. S. submarines. Capable of handling any kind of storage battery work. Can be released from Navy within a month. Salary $2400.

1450. Electrical Engineer, university graduate, age 32, 18 months electrical test, 1 year installation of hydraulic and electrical machinery in 40,000 kw. plant. Two years operation, testing and maintenance of electrical machinery with large mining company. Foreign service as Army officer. Desires position where energy, hard work and ability will produce additional responsibilities. Available now. Salary $3000.

1451. Have you an opening in your organization for an energetic, capable young man who has initiative and can produce? Has degree of B. S. in Electrical Engineering (1919) and desires to connect with an electrical concern. Just completed the layout of power and light for twelve buildings and consisting of about 550 kw. of power. Age 21. Available immediately.

1452. Electrical Engineer, (1912). Two years charge electrical laboratory and meter department large power company. General engineering, inventory and appraisal, drafting, large power company. Service work G. E. Co. Two years transformer design, one year a-c. motor design; present assistant charge motor design, consulting and quotation. Salary $2400.

1453. Graduate Electrical Engineer (Columbia 1906) with 12½ years experience with large light and power companies and manufacture of high tension electrical control apparatus, desires position. Available on short notice. Salary $3500.

1454. Ambitious young man, age 24, desires position in engineering department of firm where advancement is rapid. Good technical education. At present taking a course in engineering; 3 years office experience; 4 years in maintenance department of telephone company. Present salary $2000. Location near New York City. Available on short notice.

1455. Graduate Electrical Engineer, American, age 32, Mem. A. I. E. E., five years American manufacturing experience, two years chief engineer for large European electrical manufacturer, desires to connect with an American firm. Salary $3000.

1456. Graduate Engineer, B. S. in E. E., M. E., and C. E. Four years general industrial engineering experience. Has proven engineering and executive ability. Practical, energetic, progressive American, with excellent personality, understanding use of technical education. Position desired in New York area with growing industrial or business establishment where success will be appreciated. Salary $2200.

1457. Electrical Engineer, 1919 graduate, with seven years pre-college experience in power plant operation and construction. Single, age 23, salary $125.

1458. Electrical Engineer, graduate of recognized technical school, desires position in production or purchasing department of a growing manufacturer or utility company. Location—Ohio or adjoining states. Nine years experience in the method of production, purchase and acquainted with equipment and cost. Married. Age 34. Salary $3000.

1459. American citizen, French born, age 30. Speaks French and English, also German fluently. Traveled extensively in Europe. Five years with export firm buying and shipping electrical material. Two years assistant to inventor of electrical appliances. At present instructor in electrical machinery. Wishes connection with firm doing business with Europe as traveling or foreign representative.

1460. Engineer, age 36, university education, now in charge of department of a public utilities commission and fully experienced in financial, executive, accounting, operating, construction, appraisal and rate-fixing phases of electric, water, gas and railway utilities, desires connection with organization where this broad executive and technical ability may have unlimited scope. Salary to start $300.

1461. Electrical-Mechanical Engineer. Position desired in the development, sales or executive end of an electrical-mechanical business. Experience as follows—electrician, electrical-mechanical draftsman, chief draftsman, assistant mechanical engineer, plant engineer, head of a department of instruction. Engineering education obtained by night and correspondence schools supplemented by private instruction. Age 28, married.

1462. Graduate Electrical Engineer, age 35, thirteen years practical experience in all phases of manufacture and design of small electrical and mechanical devices, measuring and indicating apparatus. Broad experience in production and administrative lines. Desires responsible engineering or administrative position with aggressive concern introducing small apparatus for quantity production.

1463. Electrical Engineer, technical education. Former Captain of Engineers. Five years experience central station construction, operation and maintenance. Four years power and lighting installations and maintenance. Desires position with industrial concern or public utility.

1464. Electrical and Mechanical Engineering degrees. Allis-Chalmers and General Electric tests. Six years in general engineering and commercial departments of General Electric Co. At present chief engineer of hydro-steam transmission company. Prefer managing sales or engineering work. Age 35. Married.

1465. Electrical Engineering graduate, 1919, with degree of B. S., age 22, desires a position leading to experience in design or use of electrical machinery in industry or electric traction. Would also accept position with concern furnishing electric power. Have two years experience in testing d-c. machinery. Salary $30 per week.

1466. Graduate Electrical-Mechanical Engineer. Thirteen years inspection of apparatus and systems and preparation of reports in connection with patent cases. Two years plant betterment and maintenance, large cotton mill. Three years investigation industrial plants, tests, costs, rates, etc. for management corporation. Also familiar with paper and saw mills, machine shops and shoe factories. Age 42. Former Capt. U. S. A.

1467. Chemical and Electrical Engineer, Mass. Inst. of Tech. graduate, age 27, with three years experience in research, development and factory control work in a plant manufacturing several chemical products, at present employed, desires permanent position offering future in the field of electrophysics, electrochemistry, or electrometallurgy. Salary $2100.

1468. Electrical Engineer, age 28. Desires position with power company or industrial firm having large electrical apparatus such as steel mills, paper mills or mines. Three years Westinghouse test. Last eighteen months in U. S. Navy.

1469. Electrical Engineer, 32, university graduate, 7 years experience in design and constructions of power plants, substations, etc., desires permanent position as construction or designing engineer, or as mechanical and electrical superintendent in charge of installation, operation and maintenance of power plants with progressive industrial concern, factory or mine. Minimum salary $220.

1470. Electrical Engineer, age 36, married. Desires position as executive with a company where possibilities for advancement exist. Twelve years experience in general consulting engineering and valuation of public utilities, varied construction experience on gas, mechanical and electrical properties. Minimum salary to start $4000.

1471. Engineer and Executive. Twelve years consulting engineering experience with leading engineers in responsible charge of administrative and engineering work for electric properties, covering design, operation, organization, development and financial matters. Accustomed to working out difficult matters effectively and pushing things through to finish. Available November. Responsible position public utility or industrial.

1472. Graduate Electrical Engineer, experienced not only in electrical lines but with broad training and practical experience in modern physical chemistry and electro-chemistry, wishes position with manufacturer or consulting engineer; combines experience in research laboratory with factory and engineering practise.

1473. Superintendent of light or power or electrical engineer. Three years in laboratory of Boston Edison Co., and fourteen years with Stone & Webster. Excellent station and distribution experience, installing, operating, and testing on voltages up to 66,000. Can handle help and customers.

1474. Cornell M. E. Graduate (1896). Long experience as telephone, telegraph and fire protection experience, including field inspections, tests, report writing and editing; recent supervisory house and street lighting electrical construction experience; available November 1. Married. Salary $3000-$3600.

1475. Electrical Engineering Graduate, age 29, eight years active experience in electric railway and power field, desires position with public service corporation or consulting engineer. Experience has included work on both steam and hydroelectric power stations, high tension transmission lines, substations, mechanical design and construction. Recently discharged from U. S. Army.

1476. Engineering Executive—graduate electrical engineer, 12 years experience in management of public utilities, valuations, appraisals and investigations as required by Wall Street firms and State Commissions. Purchase and production, manufacturing two years electrical officer (senior lieutenant) U. S. Navy. Desires connection with live organization requiring combination of engineering, business and financial experience. Age 33.

1477. Electrical Engineer desires position with company operating railway and lighting properties or with other corporation in engineering capacity. Sixteen years experience in construction and operation of utilities, latterly in executive positions. Ex-Major, Construction Division, U. S. Army.

1478. Commercial Electrical Engineer desires position, age 30, technical graduate, four years commercial experience with central stations, four years manufacturing, erection and maintenance. Served as engineering watch officer aboard U. S. Navy Transport.

1479. College Graduate, electrical engineering course, desires managerial position with company which operates diversity of public utilities. Experienced in engineering and operating problems of electric, gas and heating utilities. Familiar also with rate-making and valuation methods. Age 32. Salary $3000.

1480. Graduate Electrical Engineer (33) with several years varied experience, wishes development, investigation, or other work of the general nature of laboratory work. Location New York City or vicinity. Minimum salary $200.

1481. Graduate Electrical Engineer (Brazilian) with varied experience in electrical machinery in the U. S., speaking several foreign languages, traveled in European and South American countries, married, 27, desires position with going concern as commercial engineer. Thorough knowledge of Brazil. Capable of acting as representative and developing trade which requires a first hand knowledge of the Latin Americas.

ENGINEERING SOCIETIES LIBRARY

The library, which comprises the individual libraries of the American Institute of Electrical Engineers, the American Society of Mechanical Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Civil Engineers, and the United Engineering Society, is located on the thirteenth and fourteenth floors of the Engineering Societies Building. In addition to engineering works it contains general reference books on allied sciences such as Physics, Mathematics and Chemistry. The library also contains publications of practically all the engineering societies in the world as well as current and bound sets of more than 1,000 engineering periodicals in English and other languages.

In order to place the facilities of this great engineering library at the disposal of persons residing out of town, a Library Service Bureau has been established, and a staff of expert searchers and translators is prepared to cover almost any engineering topic. Charges for service are at actual cost. Photostat copies of prints, drawings, etc., are $0.25 per 10 x 14 inch sheet.

All communications should be made as definite as possible so that the information received may be what is desired and not include collateral matter of no interest. The time spent in searching for such collateral matter will be saved, and information sent more promptly and in more usable shape.

Members who so desire will be kept informed regarding current publications on any engineering subject for a small annual fee.

The library is conducted as a free public library of reference. It is open to the public from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a.m. to 6 p.m.

Book Notices.—(September 1–30, 1919) Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

AIR NAVIGATION:

Notes and Examples. By Captain S. F. Card. N. Y., Longmans, Green & Co.; Lond., Edward Arnold, 1919. 140 pp., illus.,,tab., map, 9 x 6 in., cloth, $3.40.

An elementary text-book of navigation for airplane pilots, which presents the methods and the course of instruction used in training the officers of the British flying services.

APPLIED MECHANICS:

By Fuller and Johnston. Vol. II. Strength of Materials. 1st edition.

N. Y., John Wiley and Sons, Inc.; Lond. Chapman & Hall, Ltd., 1919. 556 pp., illus., 9 x 6 in., cloth, $3.75.

Volume I of this text-book, treating of statics and dynamics, appeared several years ago. The present volume, treating of the strength of materials, covers the fundamentals of this subject, as taught in the engineering departments of the Massachusetts Institute of Technology, in so far as they are required in the study of structural and machine design and in the ordinary problems of engineering practise.

CHILTON TRACTOR INDEX. July, 1919: Published semi-annually by the Chilton Co., Phila. 500 pp., 10 x 7 in., paper, $1.00.

This volume is a directory of the American tractor industry, in which, the editors state, they have attempted to present all the information useful to the industry as a whole. It includes descriptions of power farm machinery, illustrated descriptions and specifications of tractors and farm implements, and directories of manufacturers of implements, tractors, parts and accessories.

CONCRETE-STEEL CONSTRUCTION: Part I. Buildings. A Treatise upon the Elementary Principles of Design and Execution of Reinforced Concrete Work in Buildings. By Henry T. Eddy and C. A. P. Turner. 2nd edition. Minneapolis, C. A. P. Turner and Co., 1919. 477 + 25 pp., illus., tab., 9 x 6 in., cloth, $10.

The authors of this volume believe that the fundamental principles underlying the theory of reinforced construction are not generally understood by engineers and that the methods of computation of applied bending moments in common use are erroneous. Their book presents what they believe to be the correct analysis of the bending and twisting moments present in columns and flat slabs, a method founded upon the manner of distribution of the vertical shears that transmit the loading to the supports.

THE CONDENSED CHEMICAL DICTIONARY: A reference volume for all requiring quick access to a large amount of essential data regarding chemicals, and other substances used in manufacturing and laboratory work. Compiled and edited by The Editorial Staff of the Chemical Engineering Catalog. N. Y., The Chemical Catalog Company, Inc., 1st edition, 1919. 525 pp., 9 x 6 in., cloth, $5.

This volume has been prepared to meet the need for a concise summary of the properties of chemicals, which is felt by exporters, brokers, purchasing agents, manufacturers and others who require quick access to information on chemical products.

The arrangement of the book is alphabetical. The information given includes variant names, formulas, color and properties, constants (boiling and melting points, specific gravity, etc.), derivation, method of purification, grades obtainable, containers, uses, fire hazard and shipping regulations. Substances made in America are indicated. The volume is fully cross-indexed, and includes a number of useful tables of weights and measures, thermometric scales, etc. Synthetic dyes are omitted.

While the compilers state that no attempt has been made to be exhaustive, but merely to give the outstanding facts concerning the chemicals ordinarily met in commerce, approximately six thousand substances are included.

DYKE'S AUTOMOBILE AND GASOLINE ENGINE ENCYCLOPEDIA: By A. L. Dyke. 10th edition. St. Louis, A. L. Dyke. (Copyright 1919). 940 pp., illus., 10 x 7 in., cloth, $5.

It is difficult to imagine any topic connected with the use or repair of automobiles which is not discussed in this comprehensive volume for repairmen and operators. Theoretical considerations are omitted, but an immense amount of practical information is supplied in concise, definite form, illustrated by numerous drawings and charts. In addition to passenger automobiles, the volume treats of trucks, tractors, motorcycles and airplanes.

FOUNDRY PRACTISE: A Text Book for Molders, Students and Apprentices. By R. H. Palmer. 2nd edition. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1919. 390 pp., illus., 40 tab., 8 x 6 in., cloth, $3.

This volume is intended primarily for purposes of instruction, rather than as a treatise for experienced foundry men. The various types of molds are explained and illustrations of the different practises are given. Cupola and air-furnace practise, foundry equipment, methods of mending and cleaning castings are also discussed.

This edition has been enlarged by the inclusion of methods for casting and molding a number of additional articles, such as engine cylinders, propellers, lathe beds and large kettles.

GEODESY: Including Astronomical Observations, Gravity Measurements, and Method of Least Squares. By George L. Hosmer. 1st edition. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall. Ltd., 1919. 368 pp., illus., tab., 9 x 6 in., cloth, $3.50.

The author has endeavored to produce a textbook adapted to a course of moderate length which would make clear the underlying principles and emphasize the theory as well as the details of field work. The methods of observing and computing given are consistent with the practise of the Coast and Geodic Survey.

IRON AND STEEL:

A Treatise on the Smelting, Refining, and Mechanical Processes of the Iron and Steel Industry, including the Chemical and Physical Characteristics of Wrought Iron, Carbon, High-speed and Alloy Steels, Cast Iron, and Steel Castings, and the Application of These Materials in Machine and Tool Construction. By Erik Oberg and Franklin D. Jones. 1st edition. N. Y., The Industrial Press; Lond., The Machinery Publishing Co., Ltd., 1918. 328 pp., illus., 9 x 6 in., cloth, $2.50.

This volume, the authors state, is not intended as a treatise for metallurgists and those engaged in the manufacture of iron and steel, but as a textbook for students in technical schools and those engaged in mechanical engineering and machine building. The book provides for these a broad, general survey of the industry, with definite practical information on the various commercial grades and forms of iron and steel products, and the particular class of service for which each is suitable.

MARINE GAS ENGINES:

Their Construction and Management. By Carl H. Clark. 2nd edit. N. Y., D. Van Nostrand Co., 1919. 136 pp., 102 illus., 8 x 5 in., flexible cloth, $2.

This volume is a small manual of convenient size, intended for those who desire a systematic presentation of the principles of operation and construction of the standard types of marine gas engines, from a practical, rather than a theoretical point of view.

The present edition has been revised to current practise, and material in oil and Diesel engines has been added.

MANUFACTURERS' INSTRUCTORS AND ADVISERS:

By Frederic Meron. N. Y., Theo. Audel & Co. (copyright, 1919). 3 vols. and portfolio, cloth, $7.

CONTENTS: No. 1, Layouts and equipments for factories. 228 pp. and portfolio of 34 plates.

No. 2, Common sense working methods in factories. 161 pp.

No. 3, The human element in organizations, 351 pp.

The author endeavors to present concisely and clearly the results of his experience in the installation, organization and operation of industrial plants, with the object of showing, by comparison and illustration, methods for increasing output and reducing expenses.

THE METALS OF THE RARE EARTHS:

By J. F. Spencer. Lond. and N. Y., Longmans, Green & Co., 1919. 279 pp., diagrams, tables, 9 x 6 in., cloth, $4.50.

This volume supplies a review of our knowledge of these metals, in which their occurrence, separation, compounds and uses are described. An extensive list of references is included, which contains, the author believes, all the important papers published on the subject, as well as most of those of lesser importance.

OSMOTIC PRESSURE:

By Alexander Findlay. 2nd edition. Lond. and N. Y., Longmans, Green and Co., 1919. 116 pp., illus., tab., 9 x 6 in., cloth, $2.15.

The author of this monograph gives an account of the theories of osmotic pressure, the methods of determining it, and the general theory of solutions. An extensive bibliography is included. In preparing this new edition, account has been taken of the results obtained by investigators during the past six years.

OPPORTUNITIES IN CHEMISTRY:

By Ellwood Hendrick, N. Y. and London, Harper and Brothers, 1919. 102 pp., 8 x 5 in., boards, 75c.

This little volume attempts to explain the relation of chemistry to our activities in general and the usefulness of chemical knowledge in various walks of life. It will serve to introduce the subject to those considering its possibilities as a profession.

PAPERS ON THE DESIGN OF ALTERNATING-CURRENT MACHINERY:

By C. C. Hawkins, S. P. Smith and S. Neville. Lond. and N. Y., Sir Isaac Pitman and Sons, Ltd., 1919. 392 pp., illus., pl., tab., 9 x 6 in., cloth, 18 shillings.

CONTENTS: Notes on the Theory and Design of Alternating-Current Generators.—The Flux Wave-form of the Turbo-alternator with Cylindrical Rotor.—Magnetic Calculations for Tapered Teeth.—Notes on the Theory and Design of the Polyphase Induction Motor.

Originating out of many discussions on technical subjects, the papers here collected find a connecting link in their common purpose, which is to deal scientifically and practically with problems arising in the design of alternating-current machinery. The point of view throughout is that of the practical designer.

THE PRINCIPLES OF ELECTRIC WAVE TELEGRAPHY AND TELEPHONY:

By J. A. Fleming. 4th edition. Lond. and N. Y., Longmans, Green and Co., 1919. 707 pp., illus., pl. tab., 9 x 6 in., cloth, $14.

Dr. Fleming's well-known treatise has been again revised by additions which bring it up to date, while antiquated matter has been deleted in order that the volume might not become unwieldy.

The book is a statement of principles rather than a full account of actual apparatus, and is intended to provide a comprehensive view of the subject, particularly with regard to its scientific side, and of that part of it which is concerned with quantitative measurements and the underlying theory.

PERSONAL

COLONEL T. H. DILLON of the Engineers Corps of the United States Army, has resigned from the Army and accepted an appointment to a professorship of Electrical Engineering at the Massachusetts Institute of Technology.

Colonel Dillon graduated from West Point in 1904, and was appointed to the Engineers Corps of the Army. After some military duties he was assigned to the Engineer School of Application of the United States Army, from which he graduated in 1907. He was in Cuba during the American occupation as assistant to the Director of Public Works. He was occupied in the Philippines on the military survey of the Island of Luzon. He was later made electrical engineer of the Panama Canal and superintendent of the Gatun Locks. In 1918 he went to France as Colonel in command of the 37th Engineers.

C. K. CARR, for the last four and a half years Inspector of War Supplies in the Munition Dept., of the British War Mission, has resigned his position, and is now connected with the Staff of Engineers in Plant No. 2 of the Firestone Tire & Rubber Co., Akron, Ohio.

E. H. MARTINDALE has resigned his position as Sales Engineer with National Carbon Company to devote all of his time to The Handy Supply & Manufacturing Company, Cleveland, Ohio, of which he is President & General Manager. During the war Mr. Martindale was a Captain of engineers and served one year in France.

WILBUR H. THOMPSON, for the past year and a half works manager of the Fairmont Mining Machinery Company, Fairmont, W. Va. and previously prominent in heavy traction work with the Westinghouse Electric Company, has been appointed works manager of the Triumph Electric Company, Cincinnati, O.

HAROLD H. SMITH, formerly electrical engineer with the Edison Storage Battery Co. has severed his connection with that company to become Chief Engineer of the Transportation Engineering Corp., 200 Fifth Ave., New York. The Corporation acts as railway distributor for Edison Storage Batteries, "Automatic" industrial trucks and tractors and accessories.

H. G. Thompson formerly Vice-President and General Sales Mgr. of the Edison Storage Battery Co. has also resigned and has been associated with Mr. Smith in the organization of the Transportation Engineering Corp. of which he is President.

L. S. HORNER, Vice-President of the Acme Wire Company, New Haven, Conn. has just been honored with a special citation, received from the British Government, awarded in recognition of his war work as Chief of the Executive Staff of the Bureau of Aircraft Production, engaged in the development and production of aircraft during the World War.

Harry Barker announces his association with Robert C. Wheeler for the practise of engineering and the establishment of their office at 1512 Maiden Lane Bldg., 170 Broadway, New York. Special attention will be given to public utility engineering, including valuations, rates, operation and management, hydraulics, sewage and sewage disposal, water supply; city transportation; development of new processes, etc.

OBITUARY

Charles E. Lord, general patent attorney and manager of the patent department of the International Harvester Company, died on September 25 as the result of an automobile accident.

Mr. Lord was born in 1875 at Somerville, Mass. graduating in 1898 from M. I. T. with B.S. degree. For a short time he was employed in Philadelphia by the A. T. & T. Co. and then returned to M. I. T. for a short period as instructor. He then became assistant examiner in the U. S. patent office at Washington. In 1902 he entered the employ of the G. E. Co. as assistant attorney in the patent dept. and in 1904 resigned to take charge of the patent depts. of the Bullock Electric Co. and the Allis-Chalmers Co. He became president of the Bullock Co. He studied law at Georgetown Univerity and was admitted to the bar. On June 1, 1912 Mr. Lord took charge of all Harvester patent and trade-mark business.

Mr. Lord was a member of many engineering and technical societies and became a Fellow in the Institute in 1912.

Charles L. Easton, superintendent of the Midland Counties Public Service Corporation, Santa Maria, Cal., and the San Joaquin Light & Power Corporation, Santa Maria, Cal., died very suddenly at his home on October 5th as the result of heart failure brought on by a previous attack of influenza.

Mr. Easton, who gained his knowledge of electrical engineering solely through practical experience combined with home study, associated himself with the San Joaquin Light & Power Corp. in 1901 as substation operator. In 1910 on the expansion of the San Joaquin properties Mr. Easton became superintendent of the southern division, which position he held until 1917, when he was made electrical superintendent of the coast properties. He became an Associate in the Institute in 1911.

ADDRESSES WANTED

Any reader knowing the present address of any of the following members is requested to communicate with the Secretary at 33 West 39th Street.

George H. Groce
(former address)
2857-59 S. Halstead St.,
McFell Signal Co.,
Chicago, Ill.

Ernest Kardos,
(former Address)
156 E. 116th St.,
New York, N. Y.

A. B. McCollum,
(former address)
4030 Lindell Blvd.,
St Louis, Mo.

Wm. A. Street,
(former address)
Gatun, C. Z.

E. W. Sundberg,
(former address)
6912 Page Ave.,
St. Louis, Mo.

ASSOCIATES ELECTED OCTOBER 10, 1919

Abbott, Robert L., Head of Testing Dept., Sprague Electric Works of Gen. Elec. Co., Bloomfield, N. J.

Airey, Frank J., District Manager, Pacific States Electric Co., 236 S. Los Angeles St., Los Angeles, Cal.

*ANDERSON, ROBERT T., Asst. to Director, Light & Heat Station, Univ. of Pennsylvania; res., 3401 Spruce St., Philadelphia, Pa.

ARCHILA, OCTAVIO, Rua da Quitanda 56, Rio de Janeiro, Brazil, S. A.

AYMERICH, FRANK E., Lighting Specialist, Mexican General Electric Co., Apartado 403; res., University Club, Mexico City, Mexico.

BACHS, JAIME, Chief Load Dispatcher, Ebro Irrigation & Power Co., Ltd., Barcelona, Spain.

BEAN, HARRY M., Engineer, Emergency Fleet Corp., Port Newark; res., 322 Belmont Ave., Newark, N. J.

BEEBE, CHARLES F., Electrical Engineer, 813 Superior Ave. N. W., Cleveland, Ohio.

BEILER, ALBERT HENRY, Asst. Engineer, in Electrical Construction Division, Interborough Rapid Transit Co., 621 Broadway, New York, N. Y.

BENNINGTON, EARL THOMAS, President, Cuyahoga Power Construction Co., 721 W. Superior St., Cleveland, Ohio.

*BISCHOFF, HENRY W., Radio Officer, Air Service, U. S. A., 63 Newtown Road, Long Island City, N. Y.

BLACK, ROBERT, JR., Chief Load Dispatcher, Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

BOOTHBY, FRANK H., Power House & Substation Operator, Portland Ry., Lt. & Pr. Co.; res., 61 E. 60th St. South, Portland, Ore.

BOYCE, B. ADAIR M., Chief Electrical Designer, Brush Electrical Engineering Co. Ltd., Falcon Works, Loughborough, Eng.

BRAINERD, ARTHUR ALANSON, Instructor, State Trade School; res., 32 Fairview Ave., Danbury, Conn.

CAMPBELL, THOMAS V., Gen. Foreman, Elec. Shipfitting Dept., Submarine Boat Corp., Port Newark, N. J.; res., Astoria, N. Y.

CAMPBELL, WALTER WILLIAM, Design & Supervision of Industrial Plants; res., 4226 Brooklyn Ave., Seattle, Wash.

CATAPANO, FRANK, Electrician, Brooklyn Navy Yard; res., 121 Mott St., New York, N. Y.

CEGAVSKE, HARRY E., Tester, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 518 Todd St., Wilkinsburg, Pa.

CHARTRAND, JOHN B., Sales Engineer, Moloney Electric Co.; res., 1470 St. Louis Ave., E. St. Louis, Mo.

CHOLET, LEON, Electrician, Printing Dept., Metropolitan Life Insurance Co., 11 E. 24th St., New York, N. Y.

COBB, HOWARD L., Radio Electrician, Radio Laboratory, Navy Yard; res., 5837 Wissahickon Ave., Philadelphia, Pa.

CONWAY, UREY WOODSON, Lieut. Commander, U. S. Navy, Navy Department, Washington, D. C.; res., 1308 Delaware Ave., Wilmington, Del.

COOPER, GEORGE S., Electrical Engineer, Richmond Light & Railroad Co., New Brighton, N. Y.

COUTANT, TRACY S., Aux. Engineer, Central New England Railroad Co.; U. S. R. R. Administration, Maybrook; res., Clintondale, N. Y.

DAVIS, HENRY A., Distribution Engineer, Rochester Ry., & Lt. Co.; res., 531 Averill Ave., Rochester, N. Y.

DE CLAMECY, PHILIPPE, Consulting Engineer, B. F. Sturtevant Co., Hyde Park; res., 1862 Beacon St., Brookline, Mass.

*DE GOICOECHEA, LUCIANO, General Contractor, Cosculluela and Goicoechea, Compostela 65, Havana, Cuba.

DOUBT, ROBERT A., Electrical Instructor, American School of Correspondence; res., 731 E. 5th St., Chicago, Ill.

DOUGLAS, ARTHUR, Overseer, Admiralty Electrical Machinery, Manchester; res., Norrisdene, Imperial Road, Matlock, Derbyshire, Eng.

DWELLE, EARL C., Foreman, Electrical Div., Field Office, Panama Canal, Balboa, C. Z.

DYER, JOHN L., Panama Canal, Balboa, C. Z.

Felix, Edgar H., Associate Editor, *Aerial Age Weekly*, 280 Madison Ave., New York; res., Bragaw, Sunnyside, N. Y.

Fell, Douglas A., 2nd Lieut., Signal Corps, U. S. Army; res., Mayville, Wis.

***Flores, Orlando**, Engineer, S. Simao-Caperio Electrical Co.; res., S. Simao, Sao Paulo, Brazil, S. A.

Fogler, William Andrews, Supt., Testing Laboratory, Philadelphia Electric Co., 226 S. 11th St., Philadelphia, Pa.

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Friedman, Leo, Electrical Tester, Diehl Mfg. Co., Elizabeth, N. J.; res., 1388 5th Ave., New York, N. Y.

Frost, Herbert H., Buyer, Elec. Supplies & Radio Eng., Sears-Roebuck & Co., Chicago, Ill.

Fuller, Harry Lawrence, Green Bay, Wis.

Geiser, John Dixon, Asst. Engineer, with H. O. Swoboda, Pittsburgh; res., 424 Center St., Wilkinsburg, Pa.

Giese, Raymond C., Electrical Engineer, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

Goller, Adolph C., Foreman, Elec. Dept., Bethlehem Loading Co., Mays Landing; res., 208 Philadelphia Ave., Egg Harbor City, N. J.

***Goudy, Maynard P.**, Maintainance Engineer, Utah Power & Light Co., Salt Lake City, Utah.

Griffith, George Milton, Draughtsman, Oklahoma Gas & Elec. Co., Oklahoma City, Okla.

Grimes, James H., Electrician, Panama Canal, Balboa Heights, C. Z.

Harrison, F. P., Electrical Engineer, Operating Supt., Blue Ridge Power Co., East Flat Rock, N. C.

***Hattis, Robert E.**, Electrical Draftsman, The Panama Canal, Balboa Heights, C. Z.

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Ides, Xenophon Demetrius, Designing Engineer, T. E. Murray, 124 E. 15th Street, New York, N. Y.; res., Butler, N. J.

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Johnson, Allgot B., Electrician (Construction), Oliver Iron Mining Co., Norway, Mich.

Johnson, Roderick J., Machinery Inspector, U. S. Shipping Board; res., 485 W. 135th St., New York, N. Y.

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McCorkle, P. C., Chief Electrician, Cerro de Pasco Mining Corp., La Fundicion, Peru, S. A.

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Molloy, Vincent L., Engineer in Charge of Substations, Electric Light Dept., Town Hall, Sydney, Aus.

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PRICE, LE ROY F., In charge of Laboratory Photometry, National Lamp Works, Nela Park, Cleveland, Ohio.

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*SHANNON, JOHN WILBUR, Electrical Engineer, Port Huron Gas & Electric Co., Port Huron, Mich.

SHAW, NEWELL N., Cable Splicer, Panama Canal, Balboa, C. Z.

SHAW, SILAS F., Supt. of Mines, American Smelting & Refining Co., Charcas, S. L. P., Mexico.

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*SWEET, GERRIT L., Sub-Inspector, Electrical Machinery Div., Navy Yard, New York; 64 Livingston St., Brooklyn, N. Y.

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TATEKAWE, HYOICHIRO, Power Station Electrical Engineer, Inawashiro Hydro-Elec. Power Co., 1st Power House, Bandai P. O., Fukem, Shimaken, Japan.

TAYLOR, HARRY T., Asst. Gen. Manager, Kentucky River Power Co., Hazard, Perry Co., Ky.

THAYER, CLEVELAND, Local Superintendent, Carolina Power & Light Co., Oxford, N. C.

THELEN, JAMES S., Asst. Supt., Victor Electric Corp., 236 So. Robey Street, Chicago, Ill.

*THOMAS, RALPH L., Electrical Engineer, Pennsylvania Water & Power Co.; res., 730 Reservoir Street, Baltimore, Md.

THORMAHLEN, ARTHUR, Electrical Engineer, Chevrolet Motor Co., Oshawa, Ont., Canada.

TRACY, ELLIS P., Draftsman (Electrical), Switchboard Dept., Condit Elec. Mfg. Co., Boston; res., 343 Main St., Medford, Mass.

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UMAR, SYED M., State Electrical Engineer, Bhopal, C. I., India.

WACKER, HERMAN, Engineering Asst., C. & P. Telephone Co.; res., 607 Walnut Ave., Baltimore, Md.

WAINWRIGHT, HERBERT, Chief Engineer, Mueller Mfg. Co., Ltd.; res., 219 Cameron St., Sarnia, Ont., Canada.

WEIR, ROBERT P., District Manager, Cutter Electrical & Mfg. Co., Traders Bank Bldg., Toronto, Canada.

WEISSER, CHAS. F., Electrician, General Electric Company, Witherspoon Bldg., Philadelphia; res., 325 Lancaster Ave., Lancaster, Pa.

WHITTICK, ROBERT BAKER, Tech. Asst., Switchgear Sales, British Westinghouse Elec. & Mfg. Co. Ltd., Trafford Park, Manchester, Eng.

WILSON, LEON THOMAS, Research Work, American Radio & Research Corporation, Medford Hillside; res., 62 Bromfield Road, West Somerville, Mass.

WOOD, JOSEPH D., D. & S. Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 417 Biddle Ave., Wilkinsburg, Pa.

YASUKAWA, DAIGORO, Managing Director, Yosukawa Electric Works, Kurosaki, Fukuokaken, Japan.

YOERG, AUGUST, JR. Elec. Engineer, Public Service Commission, 49 Lafayette St., New York; res., 722 Evergreen Avenue, Brooklyn, N. Y.

ZAPATA, MANUEL LIMINANA, Asst. Engr. in office of Dist. Engineer, Riegos y Fuerza del Ebro; res., 16 Vallirana St., San Gervasio, Barcelona, Spain.

*Former Enrolled Students.

Total 141

ASSOCIATES RE-ELECTED OCTOBER 10, 1919

BAILEY, EDGAR L., Sprague Electric Works, Detroit; res., 181 Highland Ave., Highland Park, Mich.

BILLICA, H. J., Construction & Maintenance Engineer, Power Dept., Washington Water Power Co., Spokane, Wash.

DAVIES, HAROLD C., Electrical Engineer, Hydro-Electric Power Commission of Ontario, 190 University Ave., Toronto, Ont.

JOHNSTON, A. LANGSTAFF, JR., Lieut-Commander, U. S. N. R. F., Senior Asst. Inspector of Machinery, U. S. N., Newport News, Va.

MAASS, DANIEL, Chief Electrical Engineer, The Cuba Cane Sugar Corp., Central Socorro, Pedroso, Matanzas, Cuba.

NEWNHAM, EUGENE, Engineer and Manager of Sales, Motor Div., The Robbins & Myers Co., Springfield, Ohio.

RANSOM, ALLEN EDWARD, Sales Engineer, Westinghouse Electric International Co., 165 Broadway, New York, N. Y.

MEMBERS ELECTED OCTOBER 10, 1919

BUSHNELL, OLIVER JACKSON, Supt., Meter Dept., Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

GHEGAN, JOHN J., President, J. H. Bunnell & Co., 32 Park Place, New York, N. Y.

KAISER, CHRISTOPHER, Consulting Electrical Engineer, 101 Park Ave., New York, N. Y.

Little, Douglas, Engineer, Fyvie & Stewart, Collins House, Melbourne, Australia.

Mixer, Alfred Lane, 2nd Lieut., Q. M. C., U. S. Army; res., 111 Knox St., Rumford, Me.

Stoller, Hugh Montgomery, Telephone Engineer, Western Electric Co., 463 West Street, New York, N.Y.

TRANSFERRED TO GRADE OF MEMBER OCTOBER 10, 1919

Davis, Archibald, Jr., Senior Lieut., U. S. N. R. F., St. Louis, Mo.

Hodge, George A., General Manager, Empreza Forca e Luz de Ribeirao Preto, Sao Paulo, Brazil.

Johnson, Carl E., Vice-President & General Manager, U. S. Electrical Mfg. Co., Los Angeles, Cal.

Moore, Nelson S., Electrical Engineer, Lewis and Roth Corp., Philadelphia, Pa.

Seeger, Edwin W., Electrical Engineer, Cutler-Hammer Mfg. Co., Milwaukee, Wis.

Stanley, Howard A., Superintendent, Fall River Electric Light Co., Fall River, Mass.

Stigant, Stanley A., Electrical Engineer, Merz & McLellan, Newcastle, England.

Stoltz, G. E., General Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Tabossi, Hector, Commercial Engineer, British Thomson-Houston Co., Rugby, England.

Thompson, William J., Member of firm, Thompson-Levering Co., Philadelphia, Pa.

Tremaine, A. Raymond, Manager and Chief Engineer, Depew & Lancaster Light, Power & Conduit Co., Lancaster, N. Y.

Trust, Humphrey Gerrans, Capt., Royal Marine Engineers, Civil Engineer in Chief's Dept., Admiralty, London, England.

Young, W. E., Assistant Manager, Apparatus Dept., Canadian General Electric Co., Toronto, Ont.

TRANSFERRED TO GRADE OF FELLOW, OCTOBER 10, 1919

Barnholdt, Harold L., Designing Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Morecroft, John H., Associate Professor in Electrical Engineering, Columbia University, New York, N. Y.

Morehead, John M., Consulting Engineer, New York, N. Y.

Willis, Fred W., Deputy General Manager and Chief Engineer, Tata Hydro-Electric Power Co. & Andhra Valley Power Supply Co., Bombay, India.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its regular monthly meeting, held on September 29, 1919, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Member

Aldridge, A. P., Engineer-in-Charge, Waipori Falls Power Station, Dunedin, N. Z.

Brown, Carrol G., Professor of Electrical Engineering, School of Engineering, Milwaukee, Wis.

Ferguson, Howard F., District Engineer, Republic Engineers, Inc., Youngstown, O.

Owen, Alexander C., Assistant Electrical Engineer, Public Works Department, Wellington, N. Z.

Scrivener, Robert M., District Manager, Alfred Collyer & Co., Toronto, Ont.

Weiss, Fernand C., Superintendent of Construction, Alabama Power Co., Birmingham, Ala.

Whiting, Donald F., Electrical Engineer, Special Research Division, Western Electric Co., New York, N. Y.

STUDENTS ENROLLED OCTOBER 10, 1919

10457 Dudley, C. L., Yale Univ.
10458 Strahan, R. B., Sheffield Scientific School
10459 Lohr, F. T., Brooklyn Poly. Inst.
10460 Nakamura, J., Los Angeles Polytechnic School
10461 Smith, F. J., University of Toronto
10462 Curry, A. R., Cornell University
10463 Lattin, C. L., Yale University
10464 Fuller, W. M., School of Engg. of Milwaukee
10465 Gaetano, A., N. Y. Elec. School
10466 Bonorden, A. R., Univ. of Cal.
10467 Buck, L. L., Penn. State Coll.
10468 Keefe, W., Wentworth Inst.
10469 Maurice, R. C., N. Y. Elec. School
10470 Aquadro, L. V., Stevens Inst. of Tech.
10471 Stokes, S. O., Stevens Inst. of Tech.
10472 Theimer, A., N. Y. Elec. School
10473 Greenslade, I. J., Univ. of Wis.
10474 Mahlan, A. C., Stevens Inst. of Tech,
10475 Beerjkoff, A. P., Tri-State College of Engg.
10476 Downes, G. H., Sheffield Scientific School
10477 Osterle, W. H., Univ. of Santa Clara
Total 21

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before November 30, 1919.

Adsett, F. C., Trenton, Ont.
Aimutis, F. J., E. Pittsburgh, Pa.
Allen, L. E., Ozark, Ark.
Arnold, H. B., New York, N. Y.
Ashworth, P. P., Salt Lake City, Utah
Aubrey, C. A., Bridgeport, Conn.
Balfe, J. P., Dawson, Y. T., Canada
Barker, S., St. Louis, Mo.
Barton, R. A., Portland, Ore.
Bloomfield, R. E., (Member), Bagdad, Florida
Brennan, A. H., Newark, N. J.
Brooke, G. M., McAllen, Texas
Buckley, O. E., (Member), New York, N. Y.
Burcher, R. H., New York, N. Y.
Burt, F. R., E. Pittsburgh, Pa.
Campbell, J. A., New York, N. Y.
Carney, J. J., Waterbury, Conn.
Carpenter, H. H., Woonsocket, R. I.
Cathey, B. L., Detroit, Mich.
Charlton, A. M., (Member), Washington, D. C.
Clarkson, W. B., Schenectady, N. Y.
Corbin, A. G., Hog Island, Pa.
Cox, I. E., St. Louis, Mo.
Crawford, W. J., Milwaukee, Wis.
Crim, LeR. C., Hartwick, N. Y.
Dahlstrom, F. P., Worcester, Mass.
Danvers, W. K., Oklahoma City, Okla.
Deelwater, C. L., Elizabeth, N. J.
Edkins, E. V., Philadelphia, Pa.
Farrell, C. C., Philadelphia, Pa.
Foote, W. W., New York, N. Y.
Freeman, W. G., New York, N. Y.
Gardner, H. B., Cambridge, Mass.
Gardner, L. A., Hoboken, N. J.
Ginocchio, J., New York, N. Y.
Gleason, J. C., Atlanta, Ga.
Goodrich, C. M., Walkerville, Ont.
Hagerman, J. C., Hamilton, Ont.
Hall, E. D., (Member), New York, N. Y.
Harris, F. R., Lansing, Mich.
Helfrich, F. A., Baltimore, Md.
Heyman, M., New York, N. Y.
Hoffman, A. G., Schenectady, N. Y.
Hunt, C. M., New York, N. Y.
Hunter, H. V., New York, N. Y.
Hutchings, J. M., St. Louis, Mo.
Idail, M. J., Washington, D. C.
Kawamatay, T., Ithaca, N. Y.
Keller, L., (Member), New York, N.Y.
Kelly, J. F., Newark, N. J.
Kelly, P., Schenectady, N. Y.

Kent, P. J., S. Boston, Mass.
Lawrence, M. T., Schenectady, N. Y.
Le Beau, J. F., Allentown, Pa.
MacDougall, C. G., Toronto, Ont.
MacFadden, S. P., Beaumont, Texas
Mahlmeister, E. J., Jr., Philadelphia, Pa.
Marble, P. H., (Member), Port Arthur, Texas
Marich, W. D., Hog Island, Pa.
Maynard, A. R., Detroit, Mich.
Myers, M. A., New York, N. Y.
Miller, M. B., W. Lafayette, Ind.
Miller, W. J., Austin, Texas
Moyer, H. W., Philadelphia, Pa.
Murray, L. E., Porterville, Cal.
McElroy, D. W., Schenectady, N. Y.
Newbury, R. C., Denver, Colo.
Newlander, R. A., Chicago, Ill.
Newmark, M., Philadelphia, Pa.
Pardey, G. R., Boston, Mass.
Patterson, J. F., Montreal, Que.
Pittinger, P. N., Atlanta, Ga.
Racaza, V. A., Cebu, Cebu, Philippine Islands
Reinholdt, P. H., (Member), Sioux City, Iowa
Ries, C. F., Detroit, Mich.
Royden, G. T., Vallejo, Cal.
Runyon, W. McC., Jersey City, N. J.
Ryan, J. T., Pittsburgh, Pa.
Sayre, E. W., St. Louis, Mo.
Schacht, E. C., Schenectady, N. Y.
Schildknicht, A. E., Takoma Park, D.C.
Schleicher, G. B., Philadelphia, Pa.
Schmidt, J. F., Kearney, N. J.
Schoenberger, J. E., New York, N. Y.
Schwendler, R. H., New York, N. Y.
Scott, W., 2nd, Philadelphia, Pa.
Shahan, J. H., Elizabeth, N. J.
Sloan, D. McC., Raleigh, N. C.
Sparks, R. E., Chicago, Ill.
Splitstone, E. L., St. Louis, Mo.
Staehle, D., Jr., St. Louis, Mo.
Steele, J. G., New York, N. Y.
Stevens, R. B., New Orleans, La.
Stewart, R. J., Edgewood, Md.
Tashima, Y., Atlanta, Ga.
Taylor, H. O., Washington, D. C.
Todd, T., Boston, Mass.
Vodges, F. B., Schenectady, N. Y.
White, B. L., Fairmount, W. Va.
White, J. M., Lachine, Quebec
Whitefield, W. I., Roanoke, Va.
Williams, E. T., New York, N. Y.
Wilstam, A., Los Angeles, Cal.
Wright, R. H., E. Pittsburgh, Pa.
Total 104

Foreign Applications

Abrey, C. S., Sao Paulo, Brazil, S. A.
de Locht, V. L., Bruxelles, Belgium
Hill, H. C., (Member), Shanghai, China
Ithier, G., Bruxelles, Belgium
Jourdain, J., (Member), Nancy, France
McArthur, A. W. C., N. Woolwich, Eng.
Northrop, H., Camaquey, Cuba
Oikawa, H., Port Arthur, Japan
Taylor, C. S., (Member), Shanghai, China
Wadia, D. A., (Member), Karachi, India
Yensen, J., (Member), Copenhagen, Denmark
Total 11

REPORT OF SPECIAL COMMITTEE ON PUBLICATIONS

The following report was presented at the meeting of the Board of Directors of the Institute held in Philadelphia. October 10.

October 3, 1919.

To the Board of Directors of the
American Institute of Electrical Engineers.

Gentlemen:

In accordance with the resolutions adopted by the Board of Directors on August 12 relating to the report of the Committee on Development, this committee has carefully considered the Development Committee's report and the communications relating to the publications of the Institute that have been received by the President, the Secretary, the Development Committee, and this committee, up to the present time.

In general, the views expressed by the membership are overwhelmingly in accord with the suggestions in the Development Committee's report, including the publication of additional matter in the Proceedings.

In order to best meet the needs of the membership, and to promote the objects of the Institute as expressed in our constitution, namely, the advancement of the *theory* and *practise* of electrical engineering and of the allied arts and sciences and the maintenance of a high professional standing among its members, this committee recommends the following as the policy to be carried out when and as the necessary funds become available:

1. Transactions.

That the annual Transactions be continued in accordance with the long established policy; *i. e.*, with no change in size or character of contents.

2. Proceedings.

That the publication of a monthly periodical, heretofore designated "Proceedings," be continued.

3. Contents of Proceedings.

(a) That high grade engineering and theoretical papers, in full or in abstract, shall continue to constitute the major portion of the monthly periodical and that the space devoted to such papers shall be limited only by the amount of material available and the permissible expense.

(b) That the substance of discussions at Institute meetings be published.

(c) That the papers and discussions, in full or in abstract, as presented before Sections and Branches, be published as may be selected by the committee in charge.

(d) That a portion of the monthly publication shall be devoted to material relating to the engineering art, other than that which is presented in Institute papers and discussions, such as descriptions of new developments characterized by notable advances.

(e) That the publication of items relating to activities of the Institute and other organizations be continued and expanded.

(f) That some form of descriptive index of electrical engineering literature be published, with due regard to the various indexes now published elsewhere and the avoidance of undesirable duplication.

4. Title of the Monthly.

That the name of the publication be changed from "PROCEEDINGS of the A. I. E. E." to a title that will better indicate the broader scope of the proposed contents.

5. Size of Monthly Publication.

That the size of the monthly publication be increased to nine inches by twelve inches (9″ x 12″), the generally adopted standard for technical periodicals, as soon as it is found commercially practicable.

6. Advertising.

That the Institute's practise of the past twenty-five years of carrying advertisements in the monthly publication, be continued, and that, as heretofore, the editorial and advertising policies be entirely independent of each other.

7. Supervision.

That the general supervision of the monthly and annual publications, including decisions regarding the publication of articles, papers, discussions, and all other matter available for publication, be assigned to a standing Publication Committee; and that the carrying out of the policies that may be determined from time to time by the Board of Directors, be delegated to this standing committee.

Respectfully submitted,
W. I. SLICHTER, *Chairman*
N. A. CARLE
W. A. DEL MAR
F. L. HUTCHINSON
HAROLD PENDER
SPECIAL COMMITTEE
ON INSTITUTE PUBLICATIONS

The Board approved the report and authorized the President to appoint a standing Publication Committee, to formulate and carry out plans in accordance with the recommendations embodied in the report.

REPORT OF
JOINT CONFERENCE COMMITTEE
of
DEVELOPMENT COMMITTEES

The report of the Joint Conference Committee of the Development Committees of the four national societies of Civil, Mining, Mechanical and Electrical Engineers is published below together with a letter from Professor Chas. F. Scott, Chairman of the A. I. E. E. Development Committee, transmitting the report to the Board of Directors of the Institute.

October 10, 1919.

To the Board of Directors,
American Institute of Electrical Engineers.
Gentlemen:

When the Committee on Development made its report on August 12 it stated in the last paragraph that it had entered into conference with representatives of the other three National societies (A. S. M. E., A. S. C. E., A. I. M. & M. E.) A Joint Conference Committee was formed of three members of each Society. After the preliminary meeting on July 2, subsequent meetings were held at Montclair, N. J. on August 13, 14 and 15 at which we were represented by Messrs. Townley and Robinson and in New York, September 15, 16 and 17 by Messrs. Townley, Robinson and Scott. The final report of this Joint Conference Committee is submitted herewith to the Board of Directors.

The report consists of two parts, one covering public activities; the other, Society activities of common interest. The large proportion of the Committee's deliberations was concentrated on the first part and a broad guage plan for the cooperation of engineers and engineering societies in public activities which includes both local and National activities in its scope, has been elaborated. Such a plan must on the one hand present a broad vision and a general purpose; on the other hand it must present sufficient detail to indicate its feasibility. The present report aims to do both. Presumably many of the details of organization will be modified and criticism of the particular methods of carrying out details should not obscure the broad consideration of the scheme as a whole.

The tone of the meetings indicated a serious realization of the enlarging responsibilities which confront engineers and an earnest purpose to devise plans by which the common aspirations of engineers for accomplishing larger service might be realized through effective organization.

As chairman of the Committee I suggest that you consider the issuing of this report to our membership for its consideration and comment.

Further details with regard to the conferences which have been held and other matters relating to the Development Committee are contained in a report which I am sending to the members of the Development Committee, copy of which is enclosed.

Very respectfully,
CHAS. F. SCOTT, *Chairman,*
Development Committee, A. I. E. E.

REPORT

of the

JOINT CONFERENCE COMMITTEE

representing

The American Society of Civil Engineers,
The American Institute of Mining and Metallurgical Engineers,
The American Society of Mechanical Engineers, and
The American Institute of Electrical Engineers.

An informal meeting of the Conferees of the Development Committees of the four Societies was held in New York on July 2nd, 1919, at which the scope of the work was considered, and a sub-Committee on Procedure, consisting of the chairmen of the Conferees from each of the four Societies, was appointed to arrange the program for and the time and place of the first formal meeting. The Conferees subsequently adopted the name, "The Joint Conference Committee."

The Joint Conference Committee convened at the Hotel Montclair, Montclair, New Jersey, August 13, 14 and 15, and in New York, September 15, 16 and 17, 1919.

The Committee has divided its report into two parts, that covering the public activities and that covering the society activities of common interest to the four Societies.

1. CO-OPERATION IN PUBLIC ACTIVITIES

It was the unanimous opinion of those present at all conferences that one of the most important matters on which joint action can be taken is the formation of a single comprehensive organization to secure united action of the engineering and allied technical professions in matters of common interest to them.

In presenting its report upon a proposed form of organization which shall provide a voice to speak for the ideals of the profession, a hand to enforce unity of action and render the maximum of national, social and political service, the Committee presents for consideration the following plan. "The Committee emphasizes that the plan can only be valuable and enduring as the motive dominating it is patriotic, broad-visioned and unselfish, but firmly believes that all efforts toward bringing a united profession to the service of the Nation, the State and the City will bring to its members the public honor, esteem and recognition which their qualifications deserve, now relatively unacknowledged and uncompensated.

In preparing this plan the Committee has recognized that there exists in Engineering Council a tool which is engraving an honorable record on the pages of professional history, but its limitations are well known and its poverty is chronic. If desired, Engineering Council can be moulded into this organization by making it more democratic and founding it on direct representation of all engineers, rather than appointment as at present.

The great object is to provide an effective body, widely and truly representative, modestly yet adequately financed, which will be neither autocratic nor aristocratic, which will at all times stand as the representative and defender of the profession in matters affecting its honor, welfare and common interest.

The mandate for a vehicle to provide for co-operation and solidarity among engineers has been unmistakably expressed by the membership of the four Societies, through their several Development Committees. In obedience thereto the Joint Conference Committee has constructed a plan for an organization designed to perform this function by providing an opportunity to use the strength of every existing technical organization in the country, but without taking from them any of their present privileges, or in any way interfering with their respective spheres of usefulness.

Every new activity, to be effective, means work and needs money. A movement such as proposed, if undertaken without sufficient funds, would not only prove barren of results, but by failure would bring ridicule upon the profession. In advance of its organization no definite budget can be prepared. The revenues proposed are moderate, and are based on the experience of Engineering Council, which, while called upon to occupy an ever-widening field, has been continually handicapped by limited resources.

In submitting the proposed fundamentals to govern a single comprehensive organization by which the engineering and allied technical professions may become more active in their service to the public and themselves, the Joint Conference Committee would point out the following as among some of the objects to be attained by such an organization:

(1) To render the maximum of service to the nation through unity of action.

(2) To give the engineers of the country a more potent voice in public affairs.

(3) To secure greater recognition of the services of the engineer, and to provide for his advancement.

(4) To promote *esprit de corps* among the members of the profession.

(5) To provide the machinery for prompt and united action on matters affecting the profession, among which are:

Licensing and registration of engineers;
National Service Committee;
National Department of Public Works;
Conservation of national resources;
Publicity;
Classification and compensation of engineers;
General employment bureau;
Engineering Education;
International affiliation of engineers;
Industrial relations.

In the greater vision resulting from the world war it is apparent that no one alone can successfully solve the problems with which he is confronted. He needs the co-operation of his fellows. National problems demand united effort. The Joint Conference Committee believes that the greatest value of the proposed organization is in the united effort for the service of the nation, from which effort will result the greatest service to the individual.

The general plan offers a definite method of organization for public service. The Committee presents a means whereby the expressed wish of engineers throughout the land may be formulated in organization which shall make for the common weal.

The Committee submits the plan with the confident belief that it will be accepted by the four Societies, that they will make the sacriifices necessary and assume the responsibility of leadership, supporting the movement by virtue of their position in the engineering profession. A national movement by local societies is sure to come. The four National Societies can take the initiative and continue their leadership in American engineering by prompt action, or by inaction lose the prestige they now hold.

NATIONAL ENGINEERING ORGANIZATION*

Organization and Purpose.

In order that the engineering and allied technical professions may become a more active national force in economic, industrial and civic affairs, and in order that united action may be facilitated, it is desirable that there be co-operation through a single comprehensive organization. The purpose of such organization should be to further the public welfare wherever technical knowledge and training are involved, and to consider all matters of common concern to these professions. It should embrace:

Component Parts of Organization.

1. Local Affiliations, preferably under the auspices of local engineering societies or clubs, as follows:
   a. "Local Associations" or "Sections" of the national engineering or technical societies;
   b. Local engineering societies; and
   c. Other local engineers and members of allied technical professions and associates.
2. A National Council, consisting of representatives of national engineering and technical societies and of representatives of local, state or regional affiliations or organizations.

The formation of State Councils, composed of representatives of the local affiliations within the State or otherwise representative of the majority of the engineers and members of allied technical professions in the State, is desirable as conducive to co-operation and to further the objects of the National Council with which such State Councils should harmonize; and such State Councils are recommended wherever and whenever the local conditions warrant.

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*The Joint Conference Committee does not deem it desirable to select definite names for either the organization or its component parts, but believes that this should be left to the action of this organization when formed.

Delimitation of Authority.

Local Affiliations, State Councils (where formed) and the National Council, shall take action on local, state and national matters respectively, and they shall be autonomous with respect thereto. It shall, however, be the duty of the National Council to interest itself in the activities of Local Affiliations and State Councils if such activities are of national scope or affect the interest of the engineering and allied technical professions in other parts of the country; provided, that nothing herein stated shall be construed as preventing the discussion by any Local Affiliation or State Council or by the National Council of any matters of interest to engineers and members of allied technical professions.

LOCAL AFFILIATIONS

Purpose.

Local Affiliations are created to consider local matters of public welfare with which the engineering and allied technical professions are concerned, as well as other matters of common interest to these professions, in order that united action may be made possible in local matters.

Constitution.

Each Local Affiliation shall submit its constitution and by-laws and all subsequent modifications thereof to the Executive Board of the National Council for approval.

STATE COUNCILS

Purpose.

State Councils may be created to consider state matters of public welfare with which the engineering and allied technical professions are concerned, as well as other matters of common interest to these professions, in order that united action may be made possible in state affairs.

Constitution.

Each State Council shall submit its constitution and by-laws and all subsequent modifications thereof to the Executive Board of the National Council for approval.

NATIONAL COUNCIL

Purpose.

The National Council is created to consider national matters of public welfare with which the engineering and allied technical professions are concerned, as well as other matters of common interest to these professions, in order that united action may be possible in matters of national scope.

Basis of Representation.

Each local, state or regional affiliation or organization whose membership is not otherwise represented than through the national engineering or technical societies, shall be entitled to one representative to the National Council for a membership of from 100 to 1000 inclusive, and one additional representative for every additional 1000 members or major fraction thereof.

Each national engineering or technical society shall be entitled to one representative for a membership of from 200 to 2000 inclusive, and an additional representative for every additonal 2000 members or major fraction thereof.

Meetings.

The National Council shall hold a stated annual or biennial meeting. Other meetings *may* be called by the Executive Board upon its own initiative, and *shall* be called by it upon the written request of 25 delegates to the National Council, provided that all notices of special meetings shall be mailed not less than 60 days prior to the date thereof.

Terms of Delegates.

Delegates shall serve for terms of four years; provided that arrangements shall be made by the Executive Board so that an approximately equal number of delegates will be elected each year as provided in the by-laws.

National Headquarters and Secretary.

The National Council shall maintain National Headquarters with a permanent Secretary appointed by and holding office during the pleasure of the Executive Board. He shall not be a member of the Executive Board.

Elected Officers.

The following officers shall be elected by the National Council: A President to hold office for two years, who shall be ineligible for immediate reelection; two Vice-Presidents to hold office for four years, one to be elected every two years, and a Treasurer to hold office for two years.

Executive Board.

There shall be an Executive Board which shall direct the activities of the National Council in accordance with its adopted policies. It shall have such other functions as may be assigned to it by the National Council.

The Executive Board shall consist of the four officers elected by the National Council and one representative for each national society of 2000 members or less, with one additional representative from each national society for every additional 2000 members or major fraction thereof, to be selected from the membership of the National Council in each case by the national society concerned, and of a number of representatives selected from the membership of the National Council by the representatives therein of the local, state or regional affiliations or organizations, the said number to bear the same ratio to the representation of the national societies as the total membership of the local, state or regional affiliations or organizations bears to that of the national societies; provided that the numerical basis of representation shall be so changed from time to time that the membership of the Executive Board shall not exceed thirty (30).

The President and Secretary of the National Council shall be the Chairman and Secretary, respectively, of the Executive Board.

Electoral Districts.

The National Council shall divide the country into such districts or regions, as may be desirable to provide for the election of the district members of the Executive Board. In establishing these districts due regard shall be had to geographical conditions and membership.

Admission to National Council.

Any national engineering or technical society or any local, state or regional affiliation or organization desiring representation on the National Council shall submit a written request to the Secretary of the National Council which shall be accompanied by such data regarding the aims and status of the organization as the by-laws may provide.

The Secretary shall refer this request to the Executive Board which shall submit it to the delegates, together with its recommendations, for a letter ballot.

The applicant shall be admitted by a majority vote of the National Council, provided that not more than 25 per cent thereof shall vote in the negative.

Unexpired Terms.

Vacancies in the offices of the President, the Vice-Presidents, the Treasurer and in the Executive Board and delegates shall be filled as soon as feasible, by the agencies originally selecting the incumbents. Officers and delegates thus chosen shall serve for the unexpired terms.

Finances.

For the purpose of financing the National Council and its Executive Board (not for the use of local affiliations and State Councils) the following assessments shall be made:

Each national society represented on the National Council shall contribute annually one dollar and fifty cents ($1.50) per member.

Each local, state or regional affiliation or organization represented on the National Council shall contribute annually one dollar ($1.00) per member.

2. CO-OPERATION IN SOCIETY ACTIVITIES

Careful consideration was given to many points of common interest, and in the time available the Committee feels warranted in taking unanimous action on some of these topics, as follows:

1. Co-operation in Professional Activities:

The Committee recommends that the growing co-operation in the activities of the Societies be fostered. The unified operation of the libraries, the organization of Engineering Council, American Engineering Standards Committee, Engineering Foundation and Employment Service, are conspicuous examples of such common action. Joint committees for definite purposes should be established, and standing or other committees directing similar activities in the several societies would profit by conference. In this way common action may be taken or similar policies may be adopted when advantageous, thus avoiding duplication of effort. Comprehensive means should be provided for united action in other larger professional and technical matters.

2. Joint Meetings:

The Committee is of the opinion that periodic Joint meetings of the four National Societies in various localities would be beneficial in the development of social intercourse between the members and for debating matters of common interest. Furthermore such large conferences would bring the engineer forcibly to the attention of the general public.

3. Industrial Relations:

The question of industrial relations is one of the most pressing issues of the present day. It is a vital factor in the economic future of the country. It is a matter with which the engineer is peculiarly fitted to deal. In view of the great importance of the subject, and of the unique relation of the engineer to industry, the Joint Conference Committee recommends that Industrial Relations should be a major subject for the consideration of the engineering and allied technical professions. It is also recommended that support be given to educational movements, such as the Industrial Service of the Y. M. C. A. in colleges, the Americanization movement, and similar activities.

4. Personal Service Bureaus:

It is recommended that the Engineering Societies Employment Bureau be extended by providing for cooperation with the existing organizations of engineers maintaining employment service, and that upon the formation of the contemplated national organization the service be made available to the members of all constituent associations and branch agencies be established in communities where the local engineers desire to co-operate.

5. Student Organizations:

The Committee recommends that it be the duty of local associations and sections of the National Societies to promote and assist general student engineering societies in neighboring universities and technical schools, to provide carefully selected speakers, and to maintain personal contact with such societies. In view of the desirability of more intimate co-operation among engineers, consideration of the affiliation of the student branches of the national Societies into general student engineering associations is recommended.

6. The American Engineer in Foreign Service:

It is the opinion of the Committee that American engineers in foreign countries should be urged to assemble for purposes of better acquaintance and mutual help, and to fraternize with the engineers of the country in which they reside, for the promotion of world-wide co-operation.

7. Standards:

The Committee is unanimously of the opinion that the corelation of standards by the four Societies and others working with them, along the lines contemplated by the American Engineering Standards Committee, should be approved in principle; but in view of the fact that this matter is under consideration by the Boards of Direction of those Societies and the matter is well advanced, this Committee does not feel warranted in making a further recommendation.

8. Arbitration and Expert Testimony:

The Committee is of the opinion that the recommendation of the Committee on Development of the American Society of Civil Engineers in regard to arbitration and expert testimony, namely, that a committee of the American Bar Association be asked to co-operate with a joint committee of the four Societies in order to develop better practise in these matters, should be referred to Engineering Council.

9. Licensing and Registration of Engineers:

The Committee of Engineering Council that has had under consideration the licensing and registration of engineers has nearly completed its draft of a standard form for a uniform law on these matters. Since it is undesirable to duplicate this work, the Joint Conference Committee recommends that action be deferred pending the receipt of that report.

10. Patent Law:

Since the Patents Committee of Engineering Council, after due consideration, has approved the report of the Patents Committee of the National Research Council, in which definite recommendations are made in regard to the present patent system, it is deemed inexpedient for the Joint Conference Committee to take action on the subject of Patents and the Patent Law

11. Code of Ethics:

The Joint Conference Committee, after discussion of the question of a code of ethics, reached the conclusion that the matter would require extensive study and careful consideration in order to secure joint action by the representatives of the four Societies, and therefore deemed it unwise to attempt to make a report on this matter at this time.

CONCLUSIONS

The Joint Conference Committee was confronted with a multiplicity of matters inviting consideration, but in the two and a half months of its existence it has been able to consider only the more important ones. The vital matter is the general organization of engineers for public activities, a general plan for which is now submitted for the approval of the Societies.

When the four Societies shall have approved the plan, the Committee holds itself in readiness to work out the details by which it may be put into effect. The Committee has therefore adjourned to meet after this matter has been considered by the four Societies.

George G. Anderson Gardner S. Williams Richard L. Humphrey, Chairman	Conferees of the Committee on Development, The American Society of Civil Engineers.
Arthur S. Dwight Philip N. Moore John V. W. Reynders, Chairman	Conferees of the Committee on Development, The American Institute of Mining and Metallurgical Engineers.
Edwin S. Carman Dexter S. Kimball Louis C. Marburg, Chairman	Conferees of the Committee on Aims and Organization, The American Society of Mechanical Engineers.
Lewis T. Robinson Charles F. Scott Calvert Townley, Chairman	Conferees of the Committee on Development, The American Institute of Electrical Engineers.

NOTE: In addition to the above the following members have been in attendance at meetings of the Committee, but were unable to participate in the final drafting of the report: **JOSEPH W. RICHARDS** and **ALLEN H. ROGERS**, the American Institute of Mining and Metallurgical Engineers, and **CHARLES E. LORD**, The American Society of Mechanical Engineers.

There was also present by invitation **COMFORT A. ADAMS**, Engineering Council.

New York, N. Y., September 17, 1919.

The above report was presented at the meeting of the Board of Directors of the Institute at Philadelphia, October 10, and was ordered printed in the PROCEEDINGS for the information of the membership, with a request that members interested communicate their views promptly to the Institute headquarters for consideration by the committees concerned.

OFFICERS AND BOARD OF DIRECTORS 1919-1920

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*A complete list of the officers, committees and representatives of the Institute will be found in the October, 1919, issue of the Proceedings.

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*Inactive at present, due to the war.

PROCEEDINGS

OF THE

American Institute of Electrical Engineers

Vol. XXXVIII
Number 12

DECEMBER, 1919

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TABLE OF CONTENTS

Section I.—Institute Affairs

Institute Meeting in New York, December 12, 1919 411
Future A. I. E. E. Meetings 411
Future Section Meetings 412
A. I. E. E. Meeting in New York, November 14, 1919 412
A. I. E. E. Directors Meeting, November 14, 1919 413
Cooperative Research in Alloys 413
Letter from the President 414
Report of Board's Committee on Technical Activities 414
Nominations for Institute Officers for 1920-21 417
International Electrotechnical Commission 417
Franco-American Engineering Committee 417
Technical Books Including A. I. E. E. Transactions Wanted for University of Louvain 418
National Motor Truck Show and Highway Transport Conference 418
Engineering Council 419
    Report of Committee on Curricula of Engineering Schools 419
    Report of Patents Committee 420
    Research in Fatigue Phenomena of Metals 421
    Payment for Estimating 421
    New Building for Chamber of Commerce, U. S. A. 421
    Notes from National Service Committee 421
        Machine Tools for Technical Institutions 421
        The Fourteenth Census 422
        Technical News Bulletin, Nov. 21 422
Industrial Safety Codes 422
Formation of American Meterological Society 423
Engineering Service Bulletin 423
Engineering Societies Library 428
Obituary 431
Personal 432
Past Section Meetings 432
Past Branch Meetings 433
Addresses Wanted 435
Associates Elected November 14, 1919 436
Associates Reelected November 14, 1919 438
Members Elected November 14, 1919 438
Fellows Elected November 14, 1919 439
Transferred to Grade of Member, November 14, 1919 439
Recommended for Transfer 439
Applications for Election 439
Students Enrolled November 14, 1919 441

Section II.—Papers and Reports

Applicability of Automatic Switching to all Classes of Telephone Service. By Arthur Bessey Smith, New York, December 12, 1919 1335
The Searchlight in the U. S. Navy. By Ralph Kelly, New York, December 12, 1919 1369

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PROCEEDINGS

Vol. XXXVIII DECEMBER, 1919 **Number 12**

A. I. E. E. MEETING IN NEW YORK, DECEMBER 12, 1919

The 356th regular meeting of the Institute will be held in the Engineering Societies Building, 33 West 39th Street, New York on the evening of December 12, 1919 at 8:15 p. m.

Papers bearing on two distinctly different subjects have been selected for presentation and both are descriptive of subjects of general interest. Mr. Arthur Bessey Smith, engineer with Automatic Electric Co. of Chicago will present a paper entitled "Applicability of Automatic Switching to all Classes of Telephone Service." This paper is an attempt to place before engineers general information in regard to automatic telephone switching and the author states that automatic switching of telephone lines is adaptable to all classes of telephone service and offers a flexible means of solving problems.

The second paper of the evening entitled "The Search Light in the United States Navy," is by Ralph Kelly, formerly of the Bureau of Steam Engineering, Navy Dept., Washington, D. C. Until the present war, the searchlight and the various forms of signalling lights were in a much neglected state; the theory being that, provided enough money was spent on a searchlight and enough of them placed indiscriminately aboard a ship in prominent places, the results would be satisfactory.

During the war the lights have been developed, many varieties eliminated, the number aboard ship reduced about one-half and the remainder properly placed. The Navy Dept. has had a great amount of help from manufacturers and as a final plan of development has been settled upon it is believed the presentation of this plan before the A. I. E. E. will result in such criticism and suggestions as will prove of great assistance.

Both papers are published in this issue of the PROCEEDINGS and advance copies are available on request.

FUTURE A. I. E. E. MEETINGS

January 9, 1920, Chicago. This meeting will be under the auspices of the Lighting and Illumination Committee. Two sessions will be held at which the following papers will be presented: *Series Systems of Distribution for Street Lighting* by W. P. Hurley and *Multiple Systems of Distribution for Street Lighting* by Ward Harrison, and *Mixed Systems of Distribution for Street Lighting*, by C. P. Steinmetz. Detailed information in the January JOURNAL.

February 18 to 20, New York. Mid-winter Convention.

March 12, 1920, Pittsburgh. Meeting under auspices of Traction and Transportation Committee. Subject: Electric Traction.

April 9, 1920, Boston. Joint Meeting with the American Electrochemical Society. Meeting under auspices of Committee on Electrochemistry and Electrometallurgy.

May 21, 1920, New York. Annual business meeting of the Institute.

June 22 to 25, 1920. Annual Convention.

FUTURE SECTION MEETINGS

Baltimore.—December 12, 1919. Subject: "Electrochemical Industries."

Boston.—December 9, 1919. Subject: "Electric Power Transmission Cables."

January 6, 1920. Subject: "Electric Welding."

Cleveland.—December 16, 1919. Subject: "Manufacture, Testing and Electrical Characteristics of Electrical Sheet Steel." Speaker: W. J. Beck, American Rolling Mill Co.

Indianapolis-Lafayette.—December 12, 1919. Subject: "Comparison of Value of the Engineering Profession to other Professions."

January 16, 1920. Joint meeting with other technical societies.

February 20, 1920. Subject: "Problems Confronting Electric Railroads."

Ithaca.—December 12, 1919. Subject: "The One Best Way, as a Solution of the Industrial Problem." Speaker: Frank B. Gilbreth.

Los Angeles.—December 2, 1919. Subject: "Progress in Radio Communication." Speaker: F. B. Jewett.

January 20, 1920. Subject: "Automatic Substations."

February 17, 1920. Subject: "The Engineer in Industry."

Philadelphia.—December 8, 1919. Joint meeting, I. E. S. and Philadelphia Section A. I. E. E. Subject: "Automobile Headlights" by Dr. Sharp, Electrical Testing Laboratories.

Rochester.—December 5, 1919. Subject: "How Load Driving Synchronous Motors are Helping the Power Factor Situation" by Mr. Will Brown, of the Electric Machinery Co.

St. Louis.—December 3, 1919. Annual Dinner, Meeting and Election. Speaker: Col. E. J. Spencer.

Jan. 29, 1920. Technical Story of the Rotary Converter. Speaker: Mr. B. G. Lamme.

Schenectady.—December 5, 1919. Subject: "Electric Ship Propulsion." Speaker: W. L. R. Emmet, G. E. Co.

December 19, 1919. Smoker.

Fort Wayne.—November 20, 1919. Subject: "Gauges," (subject to change)

December 18, 1919. Subject: "High Frequency."

January 15, 1920. Subject: not assigned.

February 19, 1920. Subject: Autogeneous Welding."

March 18, 1920. Subject: not assigned.

A. I. E. E. MEETING IN NEW YORK, NOVEMBER 14, 1919

On the evening of November 14, 1919 the 355th regular meeting of the Institute was held in the fifth floor room of the Engineering Societies Building, 33 West 39th Street, New York. President Townley called the meeting to order at 8:15 p. m.

This meeting which was under the auspices of the Power Stations Committee, Chairman Philip Torchio, drew a representative audience of engineers interested in both the design and operaton of steam turbines. About 375 were in attendance.

President Townley opened the meeting by calling for the presentation of the papers scheduled for the evening. The three authors read their papers in full with interpolated explanatory remarks on special points of interest. Mr. J. F. Johnson of the Westinghouse Elec. & Mfg. Co. on "Present Limits of Speed and Power of Single-Shaft Steam Turbines." was succeeded by Eskil Berg of the General Electric Company on"Present Limits of Speed and Power of Single-Shaft Curtis Steam Turbines." The third and last paper was read by F. D. Newbury of the Westinghouse Elec. & Mfg. Co. entitled "Present Limits of Speed and Output of Single-Shaft Turbo-Generators."

President Townley then turned the meeting over to Chairman Torchio who called on B. A. Behrend to open the discussion. Mr. Behrend called attention to the rapid development in the size of turbine units and predicted a limiting of that development in the future due primarily to metal fatigue as a result of continued vibratory strain. Mr. Behrend was followed by W. L. Emmet of the G. E. Co. who described certain tests conducted by the G. E. Co. on rubber disks of varying thickness revolving at high speed. These tests graphically demonstrated certain of the strains occurring in such revolving disks and some unexpected resulting phenomena. Mr. Emmet was followed in the discussion by W. J. Foster, F. Hodgkinson, B. G. Fernald, G. A. Adams and Farley Osgood. Mr. Osgood presented the operators viewpoint on large turbo units and complained of an apparent lack of interest on the part of designers in the actual performance of machines after installation. Two written discussions by Prof. Gray and R. B. Williamson were presented by title only but will be included in the published discussion. The meeting adjourned at 11 p. m.

A. I. E. E. DIRECTORS' MEETING NOVEMBER 14, 1919

The regular monthly meeting of the Board of Directors of the Institute was held at Institute headquarters, New York, on Friday, November 14, 1919, at 3:00 p. m.

There were present: President Calvert Townley, New York; Past President Comfort A. Adams, New York; Vice-Presidents A. M. Schoen, Atlanta; C. E. Skinner, Pittsburgh; N. A. Carle, Newark, N. J.; Managers Charles S. Ruffner, Wm. A. Del Mar, W. I. Slichter, L. F. Morehouse, New York, Charles Robbins, Wilfred Sykes, Frank D. Newbury, Pittsburgh, G. Faccioli, Pittsfield, Mass.; Treasurer George A. Hamilton, Elizabeth, N. J.; Secretary F. L. Hutchinson, New York.

A report was presented of a meeting of the Board of Examiners held November 3, 1919; upon the recommendation of the Board, the following action was taken upon pending applications: 193 Students were ordered enrolled; 82 applicants were elected to the grade of Associate; 16 applicants were elected to the grade of Member; 1 applicant was elected to the grade of Fellow; 1 applicant was transferred to the grade of Member.

Upon the recommendation of the Finance Committee, monthly bills amounting to $12,723.57 were approved.

In addition to the above, many other matters relating to important activities and the general policy of the Institute were discussed. Reference to these matters may be found in this and future issues of the PROCEEDINGS under suitable headings.

COOPERATIVE RESEARCHES IN ALLOYS

The Division of Industrial Research of the National Research Council is arranging for the formation of a cooperative association to plan and support fundamental researches in alloys. Although much valuable work has been done in this field by scattered investigators there is no doubt that a well-planned and coordinated effort by a cooperative association working under the general guidance of the National Research Council and composed of specialists representing both the manufacturers and the more extensive users of alloys can produce additional results of great importance. The success of other industries which have supported research on a cooperative plan, such as has been done by the National Canner's Association and the Malleable Iron Manufacturers, is evidence of this.

It is planned to create a special scientific staff composed of a Director and Assistant Director of Research and a group of scientific investigators and technical experts who shall give their whole time to the work. To finance the organization each member of the cooperative association will pay $1000 a year, and all contributing members, who may be either alloy manufacturing or using individuals, firms or companies are to benefit alike by the results of the researches.

LETTER FROM THE PRESIDENT

November 6, 1919.

To the Membership of
American Institute of Electrical
Engineers.

Dear Sirs:

In round figures, as now constituted, the Institute membership comprises 8500 Associates, 1500 Members and 500 Fellows.

An examination of the constitutional requirements of the several classes of membership and only a casual review of the men who are now Associates and Members will make it clear to any one that there are a large number in these classes eminently qualified to be transferred to a higher grade.

The requirements for transfer oblige the individual to himself make application, and the purpose of this letter is to suggest to every Associate and Member that he should, first, carefully read the eligibility requirements, as set forth in the Constitution, and, second, examine carefully his own qualifications to see if he should not ask for transfer.

If any one is in doubt as to his own qualifications he might consult with others regarding the matter.

Not only will the standing of the individual be made more correct when he finds himself in the proper grade but the influence and standing of the Institute will be improved, both at home and abroad, in just so far as our membership show that they occupy the positions therein to which their experience entitles them.

I earnestly urge consideration of this matter on the part of all members.

Very truly yours,
(Signed) Calvert Townley,
President.

REPORT OF BOARD'S COMMITTEE ON TECHNICAL ACTIVITIES

In accordance with the action of the Board of Directors on August 12, certain portions of the Development Committee's report of that date were referred to the Committee on Technical Activities for consideration and recommendations. This committee submitted a report to the Board of Directors at a meeting held in Philadelphia, October 10, as follows:

To the Board of Directors,
Gentlemen:

In accordance with your instructions conveyed in a letter of the Secretary of August 21st to the Board's Committee on Technical Activities, this Committee has considered the question of activities outlined on page 15 of the Report of the Committee on Development, paragraphs a, b, and c, and desire to report as follows:

De-Centralization of Committee Activities:

At the present time, a Technical Committee is appointed with the idea that its membership is representative of the broad field covered by it, and to insure such representation, the membership is usually widely scattered geographically, and it so works out that all parts of the country are usually represented. There are possibly a few cases where a Technical Committee engaged in some particular activity might be able to secure assistance through a section where an industry is to a great extent localized, as for instance, coal mining and steel mills. In such cases, it is possible that there would be some advantage in having a local committee of a section to cooperate with the National Committee. This might be of particular value where a National Committee is collecting data and the local committee could be entrusted with following the matter up with the people concerned. However, it does not seem desirable at the present time to change our general system of Technical Committees, although there is nothing to prevent the appointment of local committees working in conjunction with the National Committee in our present arrangement. However, it will perhaps be useful to draw to the attention of the Chairmen the possibility of the appointment of such local committees, and if any National Technical Committee feels that it can obtain any assistance in this way, then it could arrange through the Secretary to have a suitable committee appointed by one or more sections.

One of the difficulties of Committee work at the present time is, that to make the Committees representative, means wide geographic distribution of membership. This practically prohibits Committee meetings so that the activity depends to a great extent on the Chairman with very little assistance from the members of the Committee. There are, of course, some exceptions but this is the general rule, and instead of a still further distribution of the work, it has been suggested that it might be desirable in the interest of securing real committee work, to sacrifice something in regard to representativeness of the membership for the purpose of obtaining men located close together who could meet at frequent intervals. This is, however, tied up with questions of Committee programs, and if such action seems desirable, it should be done on the recommendation of the Board's Committee on Technical Activities as conditions will vary from year to year.

While we do not feel that the sections can work with the Technical Committees to any great extent, it would seem desirable that the technical activities of the sections themselves be brought in closer touch with headquarters. It is the experience of all interested in the Institute work that the success of the section depends almost entirely upon the Chairman. It seems desirable that the Chairmen of the Committees should be brought in closer touch with headquarters, especially in regard to the subject of papers, and it is suggested that our by-laws be changed so that the chairmen of the sections shall become *ex officio* members of the Meetings and Papers Committee. In this way, they will perhaps receive some inspiration from the discussions of technical activities that take place at the Meetings and Papers Committee meetings, and they will frequently be able to secure for their Sections papers of high calibre that the Meetings and Papers Committee cannot use, or arrange to work into the limited number of meetings available. It is felt that in this way, we can somewhat de-centralize by assigning to sections particularly interested in some industry, papers of interest to them of Institute grade which could be published in the PROCEEDINGS as Institute papers, and such action would also encourage them to obtain from their own membership papers of this type. If the proposed distribution of meetings as suggested in the Development Committee's report be carried out, the presence of the Committee members from the sections would be of assistance to the Meetings and Papers Committee in making their recommendations for the location of the National meetings.

Papers of General Interest

It is considered by this Committee very desirable that from time to time papers of general interest should be read before the Institute, particularly papers that keep the membership advised as to the general progress of the art, and also the general development of related arts. To some extent, this has been done in the past with very great success, and we believe that such general papers have the widest interest for our membership. It would seem desirable that we should at least try and arrange to have one such paper at our mid-winter Convention and our annual Convention.

Activities of Younger Members

It does not seem feasible to formulate any definite practise for governing of the activities of the sections by the Institute directors. The success of the sections will be almost always dependent upon the initiative and ability of the Chairmen and to a lesser extent upon the Executive Committee of the section. It may be possible to assist the sections more than in the past if the proposed scheme of geographically distributed Vice-Presidents be adopted. However, it does not seem possible to do anything more than to suggest to the sections the desirability of interesting the younger members in the work and having them take some part in the Institute activities. It is undoubtedly true that the success of the Institute depends upon having as large a percentage of its membership active as possible, and i t is to be regretted that the main work is done by a comparatively small percentage at the present time. While it does not seem possible to make any definite recommendations, the desirability of keeping this before the section chairmen is evident. It also seems desirable that the technical work of the sections should be better worked out than is usual at the present time. Comparatively few sections arrange programs for any considerable period, and most of them are more or less dependent upon papers that are presented with comparatively little preparation by the authors, which is not conducive to good quality. If the Sections would prepare programs for a sufficient period in advance, we believe that it would tend to improve the quality of the papers that would be presented to them. The suggestion to have the chairmen of the sections on the Meetings and Papers Committee, we believe would also be of assistance in this respect.

Technical Committee Reports

This Committee has discussed the question of technical reports by the various Technical Committees. Most of the reports presented by the Committee at the present time are simply a statement of their activities and are of no particular value to the membership of the Institute. We are in agreement that one of the important functions of a Technical Committee is the preparation of a report on the state of the art in the particular field covered by it, and such developments as might be of interest and be worth recording. To properly report on the state of the art, it might be necessary for several committees to co-operate and the desirability of such co-operation is evident when a broad subject such as the generation and distribution of power is considered. Your Committee is considering the desirability of requesting the Power Station Committe, The Transmission and Distribution Committee, Electric Machinery Committee and the Protective Devices Committee to report upon the present state of the art of generation and distribution of electric energy. Such a program would, of course, have to be outlined very much in detail by your Committee to insure proper corelation of the reports, but it is believed that such summaries and authoritative statements made from time to time would be of great interest to the Institute membership at large. From past experience, it would seem that your Committee will have to take the initiative in obtaining such reports, but we are in agreement as to the desirability of such information being gathered by the Committees.

Yours very truly,
(Signed) Board's Committee on
Technical Activities.
W. SYKES, *Chairman*

The Directors accepted the report and adopted the recommendation that the Chairmen of all Sections be made *ex officio* members of the Meetings and Papers Committee. The Chairmen have been notified accordingly and copies of the above report have been mailed to all Section Chairmen, and all members of the Sections Committee, Meetings and Papers Committee, and Board of Directors.

NOMINATIONS FOR INSTITUTE OFFICERS FOR 1920-21

As provided in Section 20 of the Institute by-laws, candidates may now be proposed for nomination for the offices to be filled at the next annual election in May, 1920, by the petition or by the separate endorsement in writing, of not less than fifty members. The petitions or separate endorsements must be in the hands of the Secretary not later than January 25, 1920. For the convenience of members, a form of petition has been prepared by the Secretary, and copies of it may be obtained upon application to Institute headquarters. Endorsements may, however, be made by letter if the form is not available. A member is not limited in the number of candidates he may endorse in this manner.

The officers to be elected are: a President and a Treasurer, for the term of one year each, six Vice-Presidents for the term of one year each, and three Managers for the term of four years each.

The Constitution provides that "the President, Vice-Presidents and Managers shall not be eligible for immediate reelection to the same office. A Vice-President shall not be eligible for immediate election to the office of Manager."

For the information of members, the full text of Section 20 of the by-laws, governing the proposal of condidates for nomination, is printed below:

Sec. 20. In addition to the names of incumbents of office, the Secretary shall publish on the "form showing offices to be filled at the ensuing annual election in May" provided for in Article VI of the Constitution, the names, as candidates for nomination, of such members of the INSTITUTE as have been proposed for nomination for a particular office by the petition or by the separate endorsement of not less than fifty members, received by the Secretary of the INSTITUTE in writing by January 25 of each year; provided, however, that any candidate proposed for nomination by petition may withdraw his name by written communication to the Secretary, and any name so withdrawn prior to the printing of the form shall not be published.

The names of such candidates for nomination shall be grouped alphabetically under the name of the office for which each is proposed, and this by-law shall be reprinted prominently in the December and January issue of each year's PROCEEDINGS, and shall be reproduced on the form above referred to.

INTERNATIONAL ELECTROTECHNICAL COMMISSION

At the plenary session of the International Electrotechnical Commission held in London, October 20-24, 1919, DR. C. O. MAILLOUX, President of the U. S. National Committee of the I. E. C. who sailed from this country on October 8th in company with the other representatives of the Institute on the committee was unanimously elected the new President of the I. E. C. for the period of the next two years. A report of the U. S. Delegates will appear in a future issue of the PROCEEDINGS.

FRANCO-AMERICAN ENGINEERING COMMITTEE

At the invitation of the Societe des Ingenieurs Civils and a committee of the French Engineers Congress issued during the latter part of 1918, a delegation of American engineers was appointed by the four national societies, the A. S. C. E., the A. S. M. E., the A. I. M. E. and the A. I. E. E., to study with French engineers industrial rehabilitation problems. This delegation sailed for France on December 5, 1918. They returned to New York and issued their report at a joint meeting of the societies on February 10, 1919, as outlined in the March PROCEEDINGS. During the Paris sessions of the Congress a permanent Franco-American Commission was suggested.

At the meeting of the Board of Directors of the Institute on August 12 it was voted that a permanent committee should consist of an equal number of representatives from each of the four national societies.

This permanent Franco-American Engineering Committee, composed of two representatives of each of the four Founder Societies, has met and organized by the appointment of Nelson P. Lewis as Chairman. The Committee, as now constituted, is as follows:representing the A. S. C. E.: George F. Swain, Nelson P. Lewis; representing the A. S. M. E.: Charles T. Main, George W. Fuller; representing the A. I. M. E.: E. G. Spilsbury, Arthur S. Dwight; representing the A. I. E. E.: Lewis B. Stillwell, Andrew M. Hunt.

TECHNICAL BOOKS INCLUDING A.I.E.E. TRANSACTIONS WANTED FOR UNIVERSITY OF LOUVAIN

An organization has been formed in this country and England to provide a new library for the University of Louvain, to replace that destroyed by the Germans. Contributions of money and books are solicited for the purpose.

The Librarian of Congress has requested the Institute to donate a set of its TRANSACTIONS to the University of Louvain. This request was approved by the Board of Directors at a meeting held November 24, and the Secretary was authorized to endeavor to obtain donations of the volumes which are missing from the Institute's stock.

There have been thirty-eight (38) volumes of TRANSACTIONS published, twenty-nine (29) of which will be supplied from stock, the missing volumes being Numbers I, III, V, VI, VII, VIII, IX, XVII and XVIII, the last volume named covering the year 1899.

The Secretary of the Institute will be glad to hear from any members who are willing to donate any one or more of these volumes for the specific purpose of completing the set to be donated to to the University of Louvain.

The Library Board of the Engineering Societies Library has offered a selection of books from its duplicates to the American Committee and these have been gratefully accepted. In the discussion of the question by the Library Board it was suggested that many individual engineers would doubtless be glad to present books to the University, if they knew that they were wanted. Standard books on mining, construction, mechanical engineering, electricity, etc., will be very acceptable. It is not essential that these be the latest editions, although works which are antiquated should not be sent. Sets of the publications of learned and professional societies are especially wanted.

Books may be sent to the Librarian of Congress, Washington, D. C. The packages should be marked "For Louvain University." The Engineering Societies Library will be glad to forward any books sent to it for this purpose.

NATIONAL MOTOR TRUCK SHOWS AND HIGHWAY TRANSPORT CONFERENCES

The Motor Truck Sections of the 20th Annual Automobile Shows of 1920, will be held in the 8th Coast Artillery Armory, New York, January, 3rd to 10th, 1920, and in the International Amphitheatre, Chicago, January 24th to 31st, 1920. Upwards of seventy makes of motor trucks, together with trailers, parts and accessories will be displayed.

In conjunction with these great motor truck expositions, Highway Transport Conferences will be held, with sessions each afternoon and evening. Every important phase of highway transportation will be discussed by men recognized as qualified authorities. Various talks will be illustrated by motion pictures and stereoptican slides.

Manufacturers, distributors and business men are invited to attend these shows and conferences, and tickets will be sent on application, each ticket bearing the name of the person using it. Apply directly for complimentary tickets to S. A. Miles, Manager, 7 East 42nd Street, New York City.

ENGINEERING COUNCIL

REPORT OF COMMITTEE ON CURRICULA OF ENGINEERING SCHOOLS

October 15, 1919.

On August 12 the Board of Directors of the American Institute of Electrical Engineers referred to Engineering Council a portion of a report of the Development Committee of that Institute reading as follows:

"There is a universal recognition of the fact that engineers do not participate as actively or as prominently in public affairs as they should and that both the public welfare and their own individual advancement would be promoted if this condition could be rectified. There are two general reasons believed to be responsible for the existing condition, one a lack of any general organization of engineers which would facilitate their cooperation, and second, too great technical specialization in the engineering curricula of our technical schools and colleges, which tends to narrow the vision of the engineering student and start him on his career with an exaggerated idea of the importance of specialization and an insufficient appreciation of the part he must play in public affairs. The second reason, namely, a possible modification of the engineering curricula of our technical schools and colleges, while perhaps of underlying and fundamental importance, was nearly crowded off the Lake Placid program by the press of other matters. It was, however, the unanimous view of the members attending the sessions that this matter should receive early and thorough consideration by the Institute, and the following preamble and resolution were presented and adopted:

'As the individual engineer can not look for greater public recognition or individual advancement than his training and fitness warrant;

And, in the belief that the bigger development of the profession consists in broader social and public service by publicly-minded engineers;

Recognizing that on the one hand young engineers are employed for too long a period at work which does not stress their capabilities and, on the other, that the demands of industry for ever-increasing numbers of technicians must be supplied;

And having in mind the excellent precedents established by the medical and legal professions;

This committee would welcome the establishment at the earliest date practicable of a normal six-year collegiate course in engineering, two years of which at the least should be devoted to training in the humane arts and sciences including, for example, Political Science, Economics, History and General Letters the last four years being devoted to sound training in the sciences and in only the fundamentals of diversified engineering.

With or prior to such a development we would endorse a program for the marked extension of vocational training in the industrial centers in order that the needs of industry may be met.

To the accomplishment of these ends this Committee requests the appointment of representatives to serve on a Joint Committee of Engineering Organizations to promote such a national educational program as shall provide for the future necessities of the engineering profession consistent with the needs of society.' "

This portion of the report was presented by mail to Engineering Council by Secretary Flinn, August 27, 1919, and referred to this Committee. In connection with this reference the chairman of your committee has carried on considerable correspondence with the members of the committee and others, —copies of the latter correspondence being furnished to the members of the committee.

At a meeting of the Committee held yesterday, there being present Messrs. Jacobus, Ludlow and Humphreys, the recommendations of the Development Committee of the American Institute of Electrical Engineers were considered, and your committee now reports thereon as follows:

While your Committee is not prepared to recommend a six-year course for the Colleges of Engineering of the U. S., your Committee calls particular attention to the fact that a six-year course was inaugurated at Columbia University some few years ago, practically on the same plan as in the case of the Schools of Law and Medicine, the technical studies of the engineering portion of the course being concentrated on the last three years and based upon three years devoted to studies leading to the B.A. degree.

The Massachusetts Institute of Technology is also conducting a six-year course in engineering, this being in addition to, and without interference with, the regular four-year course. A somewhat similar program, although perhaps less formal, is followed by the majority of the students in the Harvard University Engineering School, who first take their bachelors' degree in Harvard College, followed by two years in the engineering school. This problem is also being studied and experimented on by other Universities.

Your Committee suggests that as these practical experiments with the six-year course will furnish information not now available, any final recommendation can well be deferred until the results of these experiments can be studied and appraised.

Your Committee is now prepared to report unfavorably on the proposition to substitute the six-year course in place of the four-year course generally in the Colleges of the U. S.

Your Committee strongly endorses the proposition to extend and enlarge the facilities for vocational training throughout the U. S. and particularly in the great industrial centers; this educational work, however, to be carried on without interfering with the courses in engineering.

Your Committee also favors universal military training under proper regulations.

Your Committee does not agree that military training and vocational training should be combined, except so far as the vocational training would be found to be naturally involved in the military training.

Alex. C. Humphreys, *Chairman*
Edwin Ludlow
D. S. Jacobus
C. A. Adams

REPORT OF THE PATENTS COMMITTEE

The Patents Committee, cooperating with similar committees appointed by the National Research Council and various other technical societies has been devoting its energies particularly to securing the adoption by Congress of three bills, as follows:

H. R. 5011 providing for the establishment of a Patent and Trade Mark Office independent of any other Federal Department and for an improved program of patent procedure.

H. R. 5012 providing for an increase inthe force and salaries in the Patent Office.

H. R. 7010 providing for the establishment of a Court of Patent Appeals to consist of a Chief Justice and six Associate Judges.

Another bill has been introduced in the Senate, known as S. 2332, and a corresponding bill in the House: "to create a Department of Public Works and define its powers and duties." This bill proposes to change the name of the Executive Department now designated as the "Department of the Interior" to the "Department of Public Works" and provides that the Patent Office now subordinate to the Department of Interior should be subordinate to the Department of Commerce.

No action has been taken in con ection with this bill, but as it is antagonistic to the proposition of H. R. 5011, ChairmanCharles A. Terry of Engineering Council's Committee expresses the view that so much of the bill S. 2232 as contemplates making the Patent Office a part of the Department of Commerce should be opposed for the reason advanced in favor of the adoption of H. R. 5011.

RESEARCH IN FATIGUE PHENOMENA OF METALS

An agreement between Engineering Foundation, the Trustees of the University of Illinois, and the National Research Council acting as agents of the National Academy of Sciences has been entered into for a cooperative investigation of the Fatigue Phenomena of Metals by the University through its Engineering Experiment Station.

The University will furnish room for this investigation, together with heat, light, power and water and will permit the use of such laboratory apparatus as is available. Professor H. F. Moore has been delegated by the University to supervise and direct the work. Engineering Foundation will provide from time to time certain funds necessary for the prosecution of the work. Results of the investigation are to be published by the Experiment Station and in the Engineering Societies' Journals.

PAYMENT FOR ESTIMATING

For the joint conference with the Associated General Contractors of America and the American Institute of Architects on the question of "Payment of Estimating" the following men have been appointed representatives of Engineering Council: Ralph Modjeski, Theodore L. Condron and Samuel G. Weiler, all of Chicago.

NEW BUILDING FOR CHAMBER OF COMMERCE, U. S. A.

The Chamber of Commerce of the United States is preparing to erect a building in Washington, D. C., to serve as the permanent National headquarters. This building will be a large and dignified structure, and is designed to commemorate the part taken by American business and industry in the Great War. The site selected for this building is at the corner of Connecticut Avenue and H Street, just across Lafayette Square from the White House, the State War and Navy and other Government buildings, in the very heart of the Nation's capital. Of dignified classical architecture, the building will be five stories high, and is estimated to cost $2,500,000. Mr. Cass Gilbert, of New York, is the architect.

Engineers are interested because Engineering Council is a member of the National Chamber, and as such has the privilege of using all the facilities of the Chamber's offices in Washington for the benefit of its member societies. The site for the new building has been purchased, and a campaign to raise the balance of the funds needed is soon to be made. Engineering Council bespeaks the cooperation with the Chamber of such engineers throughout the country as can help. Mr. Harry A. Wheeler, Vice-President of the Union Trust Company, Chicago, Illinois, is the chairman of the Committee on Financing Building.

NOTES FROM NATIONAL SERVICE COMMITTEE

Machine Tools for Technical Institutions

The Senate passed a bill providing for distribution of surplus machine tools to educational institutions at 20 per cent of their cost, minus the cost of their delivery. The House passed a separate bill providing for distribution of these same tools at 10 per cent of their cost price, plus transportation charges. The bill as agreed to in conference, provides "That the Secretary of War is authorized under such regulations as he may prescribe, to sell at 15 per cent of their cost.. The money realized from the sales may be used by the Secretary of War to defray expenses, except cost of transportation, incident to the distribution of these tools ...."

The Machine Tool Section of the Office of Director of Sales, War Department, is in receipt of a large number of inquiries and tentative orders for these tools. They were prepared to make shipments as soon as the bill became law, since it had been anticipated for sometime that the measure would eventually pass.

THE FOURTEENTH CENSUS

Pamphlets of instructions to enumerators for the fourteenth census have been sent to the 80,000 people engaged in this work. These instructions cover a special classification of technical engineers so that the returns will permit of their accurate enumeration. Special agents under the immediate direction of the Washington Census Bureau officials are in charge of the census of mines, quarries, forestry and manufactures.

TECHNICAL NEWS BULLETIN NO. 31

In Technical News Bulletin No. 31, issued November 5th, the Bureau of Standards has compiled a short description of their results on the following works:—Principles of Radio Transmission and Reception with Antenna and Coil Aerials—Tests of Telephone Receivers for Radio Use—Investigation of Corrosion of Cables in St. Louis—Tests of Reinforced Concrete Floor Slabs—Durability of Cement Drain Tile in Alkali Soil—Effects of Calcium Chloride on the Strength of Concrete—Discoloration Tests of Limestone—Increasing the Speed and Color Sensitiveness of Photographic Plates—Photographing through Haze and Smoke, etc.

INDUSTRIAL SAFETY CODES

A conference on Industrial Safety Codes was held at the Bureau of Standards on January 15, 1919, at which the best method of procedure in formulating such codes was considered. A committee appointed at this conference reported on April 15, 1919, and submitted two plans, designated as Plan A and Plan B.

Plan A consisted of the preparation of safety codes under the leadership of the Bureau of Standards with the cooperative effort of all interested organizations and under the general supervision of a large and representative conference committee.

Plan B consisted in the preparation of the safety codes and other standards by appropriate sponsor bodies, but under the auspices and procedure of the American Engineering Standards Committee as enlarged under a revised constitution.

In conformity with the report of the committee above referred to, ballots were sent out for voting on Plan A or Plan B to a designated list of federal bureaus, state commissions, municipal departments, technical associations, manufacturers' associations, utility associations, associations of government representatives, associations of insurance interests, safety and labor organizations.

The result of this ballot is as follows, the voting being by organizations rather than by individual delegates: For Plan A, 25 votes were cast. For Plan B, 60 votes. Of those voting for Plan A, less than one-half indicated a likelihood of joining the Standards Committee in case its reorganization is completed. Of those voting for Plan B, three-fourths looked forward to joining the Committee. In other words, approximately 70 per cent of the ballots cast favor Plan B and about 66 per cent of the organizations voting would expect to join the enlarged and reorganized Standards Committee.

The Bureau of Standards is calling another conference to be held in Washington probably on December 5, 1919. It is intended at that time to consider the procedure which should be followed in further work on safety codes and the cooperation that can be secured among the engineering societies, government departments and other agencies that are actively concerned with safety work.

FORMATION OF AMERICAN METEOROLOGICAL SOCIETY

A new organization known as the American Meteorological Society devoted to the advancement and diffusion of the knowledge of meteorology and climatology; and the broadening of their applications in public health, agriculture, engineering, industry and commerce will hold joint meetings with the American Physical Society and the Association of American Geographers at St. Louis, Dec. 29, 1919 to Jan. 3, 1920.

Many of those interested in this proposed organization have urged strongly that the practical applications of meteorology be emphasized and that special efforts be made to interest engineers, business men, shippers, farmers, fruit growers and others whose work is closely dependent on the weather.

Opinions on organization and other matters relating to this Society will be welcome and should be addresesd to Charles F. Brooks, Weather Bureau, Washington, D. C.

ENGINEERING SERVICE BULLETIN

Opportunities.—The Institute is particularly anxious to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in this BULLETIN. The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

Services Available.—Under this heading brief announcements (not more than fifty words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period names and records will remain in the office files.

Note.—Copy for publication in the BULLETIN should reach the Secretary's office not later than the 20th of the month if publication in the following issue is desired.

All replies to either "Opportunities" or "Services Available" announcements should be addressed to the number indicated in each case, and mailed to Institute headquarters.

Engineering Societies Employment Bureau.—This is a joint bureau under the auspices of the Engineering Council. The Institute's employment service is coordinated with that of the joint bureau.

OPPORTUNITIES FOR SERVICE

V-600. Engineering graduates or men partly schooled or experienced in technical work are wanted for junior engineering and administrative positions in the larger cities of the Southeast. Immediate opportunities for advancement and good pay to start. Telephone call or write—Kendall Weisiger, Bell Telephone Co., Atlanta, Ga.

V-602. Wanted: Production and designing engineer for manufacturing corrugated steel self cooled and boiler plate water-cooled transformer tanks. Location, Middle West.

V-603. Southern university requires an Assistant Professor of Mathematics, qualified to assist temporarily in Physics. Position is a temporary one, to June 1920, with possibility of reappointment; salary $200 per month.

V-604. Competent electrical engineer desired for service abroad to design, lay out and superintend plant manufacturing long distance telephone apparatus such as Pupin coils upon which patents have expired, etc. Give full details of experience.

V-605. Southern college requires an instructor in electrical engineering; to teach alternating currents and several sections in algebra, geometry and trigonometry. If satisfactory, appointee would be given assistant professorship in E. E. next year. Salary $150 per month to start.

V-606. Sales Engineer with knowledge of or experience in outside and inside distribution construction wanted by Middle West manufacturer of distribution specialties. Salary $1800-$2000.

V-607. A well known college near New York has an opening in its electrical engineering department for a recent graduate in electrical engineering. Some teaching or practical experience required. Salary commensurate with experience and ability.

V-608. Engineering graduate, experienced in application and operation of motors and motor-driven machines, to write articles and descriptive booklets for large electrical manufacture of Middle West.

R-1956. Recent E. E. graduate, good personality, for research work in testing laboratory. Most of time for first two years will be work in laboratory and on inspection. Location, vicinity of New York City.

R-1976. Editor, must have had automotive engineering experience and have good command of English. Location, New York City.

R-1995. Designing Engineer, high grade designer, familiar with centrifugal compressors, steam turbines, special and electrical machinery, etc. Location, Massachusetts.

R-2006. Squad Boss, experienced in power plant and station electrical equipment and installation work. Location, vicinity of New York City.

R-2019. Instructor in Radio Transmission for Middle West university. Prefer a graduate of a first-class college with at least one year of graduate work, including mathematical theory of electricity, particularly of radio and transients; practical military experience desirable, but not essential. Salary $2000 for nine months, with increase and promotion.

R-2021. General Engineering Draftsman, familiar with general plant layout work, piping, industrial equipment, etc. Location, vicinity of New York City. Salary, depends upon man.

R-2026. Electrical Draftsman, experienced in radio work. Location, New York City.

R-2050. Electrolytic Refining. Competent man with experience covering the principal departments of electrolytic copper refining. Must be prepared to go to Europe if necessary. State terms in application, also experience in design, construction and operation.

R-2056. Electrical engineering executive, to take charge of design and manufacture of line of electrical machinery with old established concern. Must have had experience in the electrical field; technically trained man preferred. Give details in first letter. Middle West.

R-2063. Engineer Executive. Comparatively young man, must be good executive, possess tact, be able to handle labor and must know something about machinery, electricity and chemistry. Position is in a plant located in central New York, making use of a simple electrochemical process.

R-2069. Assistants in Metals Testing Laboratory. College graduates desired. Location, Illinois.

R-2072. Editor. Young graduate engineer about 25 years of age for generalral publicity work. Location, New York City.

R-2075. Instructor in Physics. Engineering college, vicinity of New York City, has opening for engineering graduate capable of teaching physics. Position offers the advantage of a thorough grounding in science and an excellent opportunity of advancement to a satisfactory commercial position.

R-2080. Asst. Professor of Electrical Engineering desired in Middle Western University. Qualified to assume charge of central station and electric railway courses. Experienced engineer who has carried on investigative work resulting in contributions to the art is required. Opening in January.

R-2081. Instructor in Electrical Engineering for Middle Western University. Man with thorough knowledge of fundamental electrical theory and a few years experience in teaching desired. Vacancy early in February. Salary $1500-$1800 for nine month school year.

R-2091. Junior Draftsman. Must be able to do electric power plant work. Location, New York City, Salary $35.

R-2095. Maintenance Engineer, preferably man with technical education, with at least ten years experience in the field after graduation. Should have working knowledge of industrial engineering, as plant layout, design of mechanical equipment, steam piping, steam hammers, rolling mills, engines and electric motors. Steel mill experience advantageous but not essential. Good opportunities for further advancement. Location, Pennsylvania.

R-2100. Recent technical graduate, with some practical engineering experience for engineering correspondence, bulletin and price list work on pumping machinery. State education, experience, salary expected, and how soon available. Service man preferred. Location, Massachusetts.

R-2103. Electric Testing Engineer. Recent graduate or man with one to three years' experience, for general testing work in the laboratory of a large manufacturing company. Location, Pennsylvania. Salary, $100 up, depending upon experience. Several openings.

R-2114. Instructor and Writer. Capable of handling correspondence course. Openings in all branches of engineering, as civil, mechanical, electrical, mining, chemical, architecture, etc.

R-2115. Recent E. E. graduate. Young man with college training in fundamentals of electrical engineering and physics of light, to take up practical illuminating engineering in connection with incandescent lamps. Pleasing personality and ability to speak and write fluently important. Location, New Jersey. Salary to start—$1200 to $1500, according to qualifications. Extended experience not necessary; training will be given.

R-2123. Electric Equipment Engineer. To have general charge of laying out, planning and supervising electrical equipment in rapidly expanding power plan of a manufacturing company. Must be able to lay down policy for expansion and additions. Knowledge of steam power plants desirable. Location, vicinity of New York City.

R-2127. Young Electrical Engineer, with two or three years experience, for large industrial corporation located in New Jersey. Apply by letter, stating in detail education, age, experience, time available, minimum salary, etc. Several openings.

R-2128. Physicist. For brush research work. Must have the best mathematical and electrical engineering training, and combine theoretical training with a natural aptitude and practical ability in laboratory manipulation and machine design. The work consists in developing methods and tests which shall suitably relate the physical properties of brushes, such as contact drop, electrical resistance, thermal conductivity, friction, hardness, etc. to the commutation characteristics of the different types of motor generators and alternating-current machines. Location, Cleveland, O.

SERVICES AVAILABLE

1482. Graduate Electrical Engineer, age 30, married, aggressive and ambitious, with executive ability. Ten years experience with power companies and industrial plants as construction supervisor, technical correspondent and engineer. Desires position with real future, preferably along consulting or industrial engineering lines. Present location New York State. Salary to start $3000-$3600.

1483. Electrical and Radio Engineer, age 26, married university graduate, member A. S. M. E., I. R. E. Four years experience in station layouts, design of keys, relays, switches, transformers and high frequency apparatus. Is desirous of securing position as designer or supervising draftsman where opportunities are offered for advancement. Salary $2800.

1484. Have just been discharged from the Army after three years service as Captain of Engineers. Ten years experience in general electrical engineering, particularly marine electrical work. Available for position at once.

1485. Electrical and Mechanical Engineer, desires position as electrical or maintenance engineer of industrial plant with progressive manufacturer, or with consulting engineer, export house or other commercial organization.

1486. Engineer, experienced in the design, construction and maintenance of power and industrial plants, high and low tension distribution, wishes position as works electrical engineer. Age 32, married, good knowledge of Spanish. Six years in present position; now employed in supervisory capacity.

1487. Graduate of Pratt Institute, three years electrical engineers' course. Married, age 26. Desires position (with opportunity for advancement according to ability) in production end of engineering. Has had six years of maintaining and repairs of electrical machinery with government. Present salary $2000.

1488. Electrical Engineer, married, wishes research position in East, preferably New York or vicinity. Experience: one year Westinghouse apprentice; two years university teaching; three years telephone transmission work; four years research engineer of large factory in charge of research, chemical and physical laboratories closely cooperating with production departments.

1489. Greek Electrical Engineer, age 26, Lieut. S. C., U. S. A., graduate American college and university, desires connection with large manufacturing or engineering concern interested in sales or enterprises in the Near East. Thoroughly familiar with the Levant. Speaks Greek, Turkish, French, Armenian. Acquainted with influential bankers and merchants in Greece and Turkey. Location abroad imperative. Salary and commission basis.

1490. Graduate in electrical engineering, married, with two years experience in engineering department of utility system, seeks position of understudying assistant to construction engineer, offering field work to develop his executive, technical and practical start made in present employ. Any where, any time, with increases as merited.

1491. Electrical Engineer, graduate E. E., 1916, age 27, married, at present in engineering office. G. E. test experience. Recently discharged from overseas service. Two years general engineering experience, including design and factory cost estimates of synchronous machines. Also substation operating experience. Prefer office position with reliable consulting engineering firm offering good opportunities for advancement. Salary $3000.

1492. To Motor and Generator Manufacturers: Designing Electrical Engineer, experienced in electrical and mechanical design of electric motors and generators, who is also capable of handling sales, wishes to correspond with reliable and progressive motor and generator manufacturer in view of a responsible position. Age 37, technical graduate, 15 years experience.

1493. Graduate Electrical Engineer with the following experience. Five years engineering work with Westinghouse; three years commercial power sales with three large Eastern power companies. During the war laid out, installed and operated all electrical work in one of the large Eastern ship building plants. Have also had over two years experience around coal mines and steel plants.

1494. Electrical Engineer, age 27, experienced in electric railway and industrial plant engineering and electrical installations aboard ships, desires position in either sales or engineering department of concern offering good chance for advancement. Now in charge of design work (electrical) for freighters and tankers. Available on short notice. Salary $3000.

1495. E. E. graduate of a prominent university, age 25, with two and one-half years' experience in power plant economics, desires position with consulting engineer, electrical or mechanical. Location preferred, New York City.

1496. Electrical Engineer, university graduate, age 33, desires position with opportunity for advancement. Six years' design and construction, central and substations with prominent companies; mechanical, coal tipple and industrial appraisal experience. Three years municipal electrical department, in charge of electrical work in connection with municipal buildings.

1497. Engineer, age 36, holding responsible position with large manufacturing company, directing high-frequency developmental and research work, desires equally responsible position in or near New York. Thirteen years' experience: G. E. test, designing, production work, factory layouts, field investigations, development work, supervision of experimental department. Salary $3800.

1498. Graduate Electrical Engineer, with one year's experience in hydraulic generation and central station work. Services available soon. Salary desired $150 per month.

1499. Electrical Engineer, technical graduate, age 22, energetic and ambitious, desires to connect with an electrical railway company. Available immediately. Salary $130.

1500. A steady worker, college engineering graduate (1917), age 24, single. Fifteen months of general engineering and business experience with a utility company. Former naval steam engineering officer. Can report immediately. Desires position with manufacturer or as an assistant to an inventor in research work. Willing to start low if there is a good future.

1501. Electrical Engineer, 25, thoroughly familiar with research methods and patent law. Graduate, competent to take charge of small laboratory or to assist in management of a large one. Engaged at present. Available in three weeks. Start $2500.

1502. Graduate Electrical Engineer. Position desired in charge of electrical maintenance with industrial concern. Have had repair shop experience, three years in mechanical and electrical design and charge of test department of factory manufacturing motors and welders. Age 32.

1503. Capable Electrical Engineer, technical graduate, seven years' varied experience including two years' General Electric test and shop, desires responsible position with manufacturer, public utility or consulting engineer. Would also consider sales work. At present employed by largest manufacturer, doing field work in New England State. Available about January 1. Location immaterial.

1504. Public Utility manager and engineer. Age 37. Technical graduate. Twelve years' experience in operation, construction, engineering and management of public utilities. Ex-Major, Construction Division, U. S. Army. Formerly employed as consulting engineer for large corporation and manager of three subsidiary companies furnishing gas, electric, refrigeration and heat service.

1505. Meter Engineer. Expert on all kinds of meters, also signal and detail apparatus; molded insulation. Technical graduate, 13 years experience, age 31; present salary $2200.

1506. Research Engineer, electrical and mechanical, having several years experience with large electrical manufacturing company, desires responsible position with aggressive concern.

1507. Engineer, for work in France Seven years general experience, mostly construction and executive; desires position as manufacturer's representative or in other engineering capacity. Salary—minimum $4000 per year.

1508. Engineer, electrical, hydraulic and steam, with 22 years experience, desires position as electrical engineer or superintendent of power houses with large central station or manufacturing company. Salary $7500.

1509. Electrical Engineer. Technical graduate. Age 35. Ten years experience—design, construction and operation, switchboards, industrial plants, public utility plants, underground and overhead work. High class work only. Desire position reconstruction or new plant work. Salary $3600 per year.

1510. Sales Engineer and Sales Executive, technically trained, ten years active experience—manufacturing, power plant design, industrial engineering and selling to the construction, also public utility and large industrial concerns. Can close up contracts, organize and follow up selling campaigns. Age 31, unmarried.

1511. Plant Engineer or Electrical Engineer or Assistant Plant Engineer in factory near New York. Technical graduate in electrical engineering. Twelve years experience; age 32; married; salary $2400.

ENGINEERING SOCIETIES LIBRARY

The library, which comprises the individual libraries of the American Institute of Electrical Engineers, the American Society of Mechanical Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Civil Engineers, and the United Engineering Society, is located on the thirteenth and fourteenth floors of the Engineering Societies Building. In addition to engineering works it contains general reference books on allied sciences such as Physics, Mathematics and Chemistry. The library also contains publications of practically all the engineering societies in the world as well as current and bound sets of more than 1,000 engineering periodicals in English and other languages.

In order to place the facilities of this great engineering library at the disposal of persons residing out of town, a Library Service Bureau has been established, and a staff of expert searchers and translators is prepared to cover almost any engineering topic. Charges for service are at actual cost. Photostat copies of prints, drawings, etc., are $0.25 per 10 x 14 inch sheet.

All communications should be made as definite as possible so that the information received may be what is desired and not include collateral matter of no interest. The time spent in searching for such collateral matter will be saved, and information sent more promptly and in more usable shape.

Members who so desire will be kept informed regarding current publications on any engineering subject for a small annual fee.

The library is conducted as a free public library of reference. It is open to the public from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

Book Notices:—(October 1-31, 1919). Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

AUTOMATIC SPRINKLER PROTECTION:

By Gorham Dana. 2nd edition. N. Y., John Wiley and Sons, Inc.; Lond. Chapman and Hall, Ltd., 1919. 456 pp., illus., 9 x 5 in., cloth, $3.50.

The author of this volume has attempted to cover the subject in such a way that his book may serve as a textbook for students and also as a reference book for experienced engineers. Starting with a historical summary of the development of the art, he then describes the tests and characteristics of sprinklers, installation rules, layouts, valves, supervisory systems, etc. An appendix lists all types on which information is available and summarizes over six thousand tests of various sprinklers.

CATALYSIS IN INDUSTRIAL CHEMISTRY:

By G. G. Henderson. Lond. and N. Y., Longmans, Green & Co., 1919. 202 pp., cloth, 9 x 6 in., $3.25.

This, the latest volume of the series of Monographs on Industrial Chemistry which is being published under the editorship of Sir Edward Thorpe, is intended to present broadly our present knowledge of the phenomenon of which it treats. The book reviews the existing literature on catalysis, paying particular attention to the many and varied applications now used in industry. The author hopes that it will also suggest the desirability of further investigations.

COMMERCIAL OILS—VEGETABLE AND ANIMAL:

With special reference to Oriental Oils.

By I. F. Laucks. 1st edition. N. Y. John Wiley and Sons, Inc.; Lond., Chapman and Hall, Ltd., 1919. 138 pp., cloth 8 x 5 in., $1.25.

This book is intended to give men without technical training, who are in the oil trade, the technical data and information required in everyday dealings, in concise form.

The various commercial oils are listed. For each are given the sources, uses, and the physical and chemical characteristics. The values have been collected from the standard texts, supplemented, particularly in regard to oriental oils, by the results obtained in the author's laboratory.

ELEMENTS OF RADIOTELEGRAPHY:

By Ellery W. Stone. N. Y., D. Van Nostrand Co., 1919. 267 pp., 125 illus., 33 pl., 8 x 5 in., flexible cloth, $2.50.

This book, by the instructor at the U. S. Naval Radio Station, San Diego, was written primarily for use in instruction at that school; it is believed, however, that it will be helpful in other schools and for self instruction.

The physical, rather than the mathematical presentation of the subject is used. A knowledge of physics and mathematics is not necessary. Prominence is given to the development of the subject as illustrated by patents.

FIFTY YEARS OF IRON AND STEEL:

By Joseph G. Butler, Jr. Cleveland. The Penton Press, 1919. 145 pp., por., 10 x 6 in., leather. (Gift of author).

This volume is one of a special edition, limited to one hundred copies, of an address delivered before the American Iron and Steel Institute in 1917, in which the author gives his personal reminiscences of the development in iron and steel making, as observed during an active participation in the industry in eastern Ohio, which began in 1857. To this are added some brief data on the early history of iron and steel, and a chapter on the activities of the American iron manufactures during the great war. The volume is profusely illustrated with portraits of men of note in the industry.

FOREST PRODUCTS:

Their Manufacture and Use, Embracing the Principle Commercial Features in the Production, Manufacture, and Utilization of the Most Important Forest Products Other than Lumber, in the United States.

By Nelson Courtlandt Brown. 1st edition. N. Y., John Wiley and Sons, Inc.; Lond., Chapman and Hall, Ltd., 1919. 471 pp., 120 illus., 1 pl., tab., cloth, 9 x 6 in., $3.75.

The object of this book is to provide a brief account of the chief commercial features involved in the manufacture and use of such products as wood pulp and paper, tanning materials, veneers, cooperage, naval stores, distilled products, charcoal, maple sugar and syrup, dye woods, rubber, cork, excelsior, shingles, mine timbers, etc., which will serve as a text for students and as a book of reference. The volume reviews a field in which, the author states, but little has been written on American practise. Brief bibliographies are appended to the chapters.

THE GASOLINE AUTOMOBILE:

Prepared in the Extension Division of the University of Wisconsin by George W. Hobbs and Ben G. Elliott. Second edition, completely revised by Ben G. Elliott and Earl L. Consoliver. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1919. 483 pp., illus., 1 pl., cloth, 9 x 6 in., $3.00.

Developments in automobile practise during the past four years have necessitated changes in this popular text-book. In addition to the necessary revision, the book has been rewritten and enlarged by the inclusion of several new chapters. In doing this the authors have provided a work on the fundamental principles of automobile design, construction and operation for the instruction of those who drive, repair, sell or otherwise have to do with motor cars.

HYDROLOGY:

The Fundamental Basis of Hydraulic Engineering. By Daniel W. Mead. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1919. 647 pp., illus., maps, tables, 9 x 6 in., cloth, $5.00.

Lack of knowledge of the fundamentals of hydrology and of the importance of hydrological factors has been responsible, the author believes, for more failures in hydraulic engineering projects than defects in structural design. To assist in removing this ignorance he has here set down some of the more important facts and principles, omitting everything that his long experience has not shown to be of practical importance. Carefully selected lists of references are appended to each chapter, to enable readers to complete their study of any phase of the subject, which has not been sufficiently treated within the limits of the book itself.

A MANUAL OF PHYSICAL MEASUREMENTS:

By Anthony Zeleny and Henry A. Erikson. 4th edition. 261 pp., 129 illus., tables, 8 x 5 in., cloth, $2.00.

This manual is an outline of the laboratory course given to students of general physics at the University of Minnesota. One hundred and thirty-three experiments are included. Directions for assembling the apparatus and performing the experiments are given. Appendixes give the mathematical tables needed by users of the book.

OXY-ACETYLENE WELDING MANUAL:

By Lieut. Lorn Campbell, Jr., 1st edition. N. Y., John Wiley & Sons, Inc.; Lond., Chapman & Hall, Ltd., 1919. 154 pp., 92 illus., 1 pl., cloth, 8 x 5 in., $1.25. (Wiley Engineering Series).

An instruction book for beginners by the officer in charge of welding instruction in the U. S. A.

Ordnance Department. The work is confined to shop practise, and is intended to provide a systematic, standardized method of instructing, adapted to class use and as a reference book in the shop.

THE PHYSICAL CHEMISTRY OF THE METALS:

By Rudolph Schenck. Translated and annotated by Reginald Scott Dean. 1st edition. N. Y., John Wiley and Sons, Inc.; Lond., Chapman & Hall, Ltd., 1919. 239 pp., illus., tables, 9 x 6 in., cloth, $3.00.

This volume is the outcome of a course of lectures delivered in the Technischen Hochschule at Aachen before the engineers of the district. The purpose of the lectures was to show the use of chemical statics and to explain the applications of physical chemistry in the study of smelting operations and metallurgical processes.

The translator has made additions to the original text when necessary and has revised the numerical data to agree with the accepted values

PRACTICAL MATHEMATICS FOR HOME STUDY:

Being the essentials of Arithmetic, Geometry, Algebra and Trigonometry.

By Claude Irwin Palmer. 1st edition. N. Y., McGraw-Hill Book Co., Inc.; Lond., Hill Publishing Co., Ltd., 1919. 493 pp., illus., tab., cloth, 8 x 5 in., $3.00.

During the past fifteen years the author has taught methematics in the evening school at the Armour Institute of Technology to classes of men engaged in practical pursuits of various kinds. For this purpose a course of instruction was published in four volumes, which has now been arranged in one volume, with particular reference to the needs of home students. In the present edition, a few new topics have been added, together with many solutions of problems.

The book includes arithmetic, geometry, algebra, logarithms and trigonometry. It is intended for adult students and the three thousand exercises and problems are selected to illustrate actual practical problems.

PRACTICAL WINDINGS OF ALTERNATING CURRENT MACHINERY:

By J. Herbert Wickman. Milwaukee. J. H. Wickman, 36 pp., 9 x 6 in., paper, $1.

This pamphlet is intended to give the necessary information to armature winders, without mathematical calculations or theoretical discussions. Directions for winding, reconnecting for other voltages or changing the windings from one phase to another are given.

PRINCIPLES OF DIRECT-CURRENT MACHINES:

By Alexander S. Langsdorf. Second edition. N. Y., McGraw-Hill Book Company, Inc.; Lond., Hill Publishing Company, Ltd., 1919. 460 pp., 314 illus., 8 x 6 in., cloth, $4.00. (Electrical Engineering Texts).

This book has been prepared to place before students of electrical engineering a reasonably complete treatment of the fundamental principles underlying the design and operation of all types of direct-current machinery. Instead of attempting to touch the "high spots" in the whole field of direct-current engineering, attention has been concentrated upon certain important features which are ordinarily dismissed with brief mention, but which, the author believes, are vital to a thorough grasp of the subject.

The present edition has been thoroughly revised and enlarged in accordance with the results of experience in the use of the book.

PRINCIPLES OF REINFORCED CONCRETE CONSTRUCTION:

By F. E. Turneaure and E. R. Maurer 3d edition, revised and enlarged. N. Y., John Wiley and Sons, Inc.; Lond., Chapman and Hall, Ltd., 1919. 485 pp., illus., diag., pl., tables, 9 x 6 in., cloth, $3.75.

Like former editions, this work is intended "to present in a systematic manner those principles in mechanics underlying the design of reinforced concrete; to present the results of all available tests that will aid in establishing coefficients in working stresses; and to give such illustrative material from actual designs as will serve to make clear the principles involved."

In the present edition the material has been considerably amplified and rearranged. Separate chapters have been devoted to the theory of flexure; bond and shear; and the design of beams. The experimental data have been reviewed. A new chapter on flat slabs has been added and the chapter on building construction extended.

RETAINING WALLS:

Based entirely on the Theory of Friction.

By Pedro Dozal. Done into English by R. T. Mulleady. 1st edit. Buenos Aires, M. A. Rosas, 1918. 161 pp., 62 illus., cloth, 11 x 7 in., (Gift of author).

The author presents a general theory in regard to the static pressures acting on a plane cutting an unbounded coherent, incoherent or liquid mass in equilibrium, and its application for the calculation of the pressures on retaining walls. The theory advanced differs from those presented by Rankine and other students of the subject and gives notably different results.

STEAM TURBINES:

A Practical and Theoretical Treatise for Engineers and Students, including a discussion of the Gas Turbine. By James Ambrose Meyer. 4th edition, revised and enlarged. N. Y., John Wiley and Sons, Inc.; Lond., Chapman and Hall, Ltd., 1919. 496 pp., illus., diag., tables, 1 folded chart, 9 x 6 in., cloth, $4.

This edition differs from the preceding ones by containing fuller discussions of the methods of governing, the calculation of the strength of disk type blade wheels, and of recent developments in marine practise. The text as a whole has also been revised. The general purpose of the volume is to provide the designer, operator or manufacturer of steam turbines with a concise manual of information, based on practical experience.

OBITUARY

WILLIAM D. WEAVER an active member of the Institute for over thirty years died at his home in Charlottesville, Va., on Saturday, November 1, 1919.

He was born at Greensburg, Pa., August 30, 1857. He graduated in 1880 from the United States Naval Academy, studying at the Sorbonne and in London. In 1883 he went on the first Greeley Relief Expedition. He founded the *American Electrician* and was editor of the *Electrical World* from 1893 to 1912. He re-entered the United States Navy as volunteer chief engineer in 1898. In 1904 he was treasurer and business manager of the International Electrical Congress at St. Louis. He was twice a director of the Institute, and from 1901 to 1906 chairman of its Library Committee. In 1915 he was selected by the Board of Directors as one of the Institute's representatives on the Naval Consulting Board, but he declined on account of his health.

In 1903 Mr. Weaver prepared and submitted to Mr. Carnegie a proposition under which Mr. Carnegie was to donate an amount for the purpose of "housing" the library and it is a matter of record that the building up of our great engineering library was largely accomplished by his exertions, guided by a most remarkable knowledge of engineering literature. The library stands today a silent monument to Wm. D. Weaver.

At the meeting of the Board of Directors of the Institute on November 14, 1919 the following resolution was adopted:

WHEREAS, on November 1st, 1919, the engineering profession sustained a great loss in the death of William Dixon Weaver, engineer, journalist and patriot; and

WHEREAS, Mr. Weaver was an honored and helpful member of the American Institute of Electrical Engineers for more than thirty years and was transferred to its highest grade of membership, that of Fellow, in 1913; served with distinction upon numerous important committees and as a member of its governing body for six years, was largely instrumental in securing a permanent home for the engineering societies, aided effectively in building up the Institute Library and rendering it serviceable to the membership, and was ever ready to lend assistance to deserving causes and men; be it

RESOLVED: That the Board of Director of the Institute hereby places on record this expression of its sorrow and its appreciation of William Dixon Weaver's long continued generous and active interest in the Institute, his sincere sympathy with its objects, and his earnest devotion to the highest ideals in the growing field of electrical science; and further be it

RESOLVED: That these resolutions be spread upon the minutes of this meeting, that they be printed in the PROCEEDINGS, and that a copy be sent to Mrs. Weaver.

The friends of Mr. L. W. Chubb, who is representing the Institute at a meeting of the International Electrotechnical Commission in London, will be shocked to learn of the tragic death of his wife, which occurred on Saturday night, November 1. Mrs. Chubb was returning home through a heavy rain storm, and stpeped from the pavement to the street to avoid a part of the pavement covered by water; and in doing so, stepped before a passing automobile, death resulting in a few hours. Mrs. Chubb leaves, besides her husband, a family of three small boys. Mr. Chubb was at once advised by cable, and is returning home at the earliest possible moment.

PERSONAL

R. De Vere Hope recently discharged from the United States Army, where he was stationed at Edgewood Arsenal in connection with the manufacture of mustard gases, has entered the organization of the Duratex Company, as Industrial Engineer. Prior to Mr. Hope's experience in the army, he was connected for a number of years with the Engineering Department of the New York Telephone Company.

John A. Ryan has been appointed Eastern Sales Manager for The Consolidated Belting Company, Philadelphia, Pa., manufacturers of leather belting for all transmission purposes.

Paul M. Lincoln, Past President of the A. I. E. E. and for years a member of the Board of Directors and upon the Transmission Committee of the Institute has resigned from his position with the Westinghouse Electric & Mfg. Co. to take active charge of motor application engineering for The Lincoln Electric Co. Mr. Lincoln designed and installed the first hydroelectric power plant at Niagara Falls and subsequently directed its operation for six years. He was connected with the development of the first high-voltage transmission lines and has patented many successful appliances in the electrical field.

W. C. Winterroth who for the past two years was sales engineer for The Mechanical Appliance Company, and located at Chicago, Ill., was recently appointed District Sales Manager for that company for the new district office in Buffalo, New York.

PAST SECTION MEETINGS

Baltimore.—October 24, 1919, Johns Hopkins University, Paper: "Signalling in War with Invisible Light" by Professor R. W. Wood. The paper was illustrated by many experiments, and several pieces of apparatus as used in the war were on exhibition. Attendance 120.

Boston.—October 14, 1919, Engineers Club. Subject: "Automatic Substations in Theory and Practise." Short illustrated talks by Messrs. W. C. Slade, Supt. of Power and Lines, Rhode Island Co., Providence, R. I.; L. B. Bonnett, C. M. Gilt, General Electric Co., Schenectady, N. Y.; and C. A. Butcher, Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa. Attendance 125.

Cleveland.—October 21, 1919, Hotel Statler Subject: "Thirty Years Development in the Electrical Industry." Speaker: Mr. Alexander Churchward, Consulting Engineer, Wilson Welder & Metals Co., N. Y. Attendance 29.

Denver.—October 18, 1919, Shirley Hotel. Subject: "Human Engineering." Speaker: Mr. Cowdrick. Past-President of the Institute, Mr. P. M. Lincoln, was present and made some remarks. Attendance 35.

November 6, 1919, El Jebel Temple. Address by Dr. Frank B. Jewett on "Some War-Time Developments in Electrical Communication." Address was illustrated by stereopticon and motion pictures. Attendance 706.

Fort Wayne.—October 16, 1919, G. E. Company Bldg. 16-2. Address by Professor John C. Parker on the present status of the engineer and also the probable future trend of engineering education. Attendance 48.

Los Angeles.—October 25, 1919, members of Los Angeles Section invited to visit the U. S. S. "New Mexico" (The Electric Ship). Ninety members and students took advantage of the inspection trip.

Lynn.—October 22, 1919, Lynn Classical High School. Subject: "Photographic Experiments in Air and on

Land." Speaker: Lieut. Parker H. Kemble, U. S. N. Lieut. Kemble dealt particularly with the photographic charting of the coast of New England. Attendance 300.

November 5, 1919. Lecture by Dr. Saul Dushman, of the Research Laboratory, G. E. Co., Schenectady, N. Y., on the "Structure of the Atom." The lecture was illustrated by lantern slides and a model. Attendance 160.

Panama.—September 6, 1919, Balboa Heights. Discussion of paper by A. E. Silver "Problems of 220-kv. Power Transmission." Attendance 31.

October 11, 1919, Balboa Heights. Talk by Mr. J. J. Henry, Senior Chief Engineer of the Dredging Division, on "Steam Turbines." Attendance 25.

Philadelphia.—November 10, 1919. Speaker: N. E. Funk. Subject: The Chester Generating Station of the P. E. Co. Illustrated by the use of lantern slides. Attendance 86.

Pittsburgh.—October 14, 1919, Chamber of Commerce Auditorium. Paper: "Some Experience in the Development and Introduction of Submarine Detection Devices" by C. E. Eveleth. Attendance 56.

St. Louis.—October 29, 1919, Engineers Club. Joint meeting with the Associated Engineering Societies of St. Louis. Illustrated talk on "Static Condensers" and their application to power factor correction. Attendance 51.

Schenectady.—October 17, 1919, Edison Club Hall. Address by Dr. C. P. Steinmetz on "Technical Education." Mr. L. T. Robinson, the Section's representative on the Committee on Development, gave a resumé of the work of the Committee on Development to date, which was followed by general discussion. Attendance 325.

November 7, 1919, Edison Club Hall. Address by F. G. R. Gordon, Secretary of the American Anti-Socialist League, on "A Study of Socialism." Attendance 275.

Toronto.—October 24, 1919, Engineers Club. Paper: "Turbine Design," presented by Mr. A. Aeberli. The paper was graphically illustrated by diagrams showing the methods employed in designing. Mr. F. R. Ewart gave a brief report on the work of the National Industrial Conference, which he attended as delegate of the Toronto Section. Attendance 77.

Washington.—October 14, 1919, Cosmos Club. Paper: "Submarine Detection" by Prof. John B. Whitehead. Attendance 110.

November 11, 1919, Cosmos Club. Paper: "The Motion Pictures of the Invisible" by Mr. James Hardy, Vice-President of the Bray Studios, N. Y. Attendance 160.

PAST BRANCH MEETINGS

Brooklyn Polytechnic Institute.—October 31, 1919, Polytechnic Institute. Paper: "Transformers" by Prof. D. M. Cushman. Attendance 35.

University of California.—October 8, 1919. Talk by H. C. Silent on "Principles and Development of the Radio Telephone." Attendance 29.

October 22, 1919. Talk by Mr. D. I. Cone on "Engineering Aspects of Telephonic Transmission." Attendance 32.

Carnegie Institute of Technology.—October 21, 1919, Machinery Hall. Election of officers as follows—Chairman K. K. Knaell, Vice-Chairman Wm. A. Keller, Treasurer W. J. Brennan, Permanent Secretary B. C. Dennison. Addresses: (1) "Purposes of the Organization by B. C. Dennison." (2) "Experimental Work at the Bureau of Mines" by W. V. Wolfe. (3) "Experiences with the Royal Flying Corps" by W. J. Blanko. (4) "My Experiences in the Service " by Messrs. H. T. Goldberg, L. H. Hale, F. I. Lawson and R. N. Jones. Attendance 20.

University of Cincinnati.—October 21, 1919, Eng. Bldg. Organization meeting. Attendance 87.

October 28, 1919, Eng. Bldg. Talk by Dr. R. C. Gowdy on "Some Problems in Physics Worked on During the War." Attendance 91.

Clemson College.—October 21, 1919, Electrical Engineering Class Room. Talks: (1) "Outdoor Illumination" by A. F. Holley. (2) "Life of Edison" by R. B. Bratton. (3) "Current Events" by M. J. Black.

Kansas State Agricultural College.—October 9, 1919. Papers: "Coal Mining in the Central States" by C. F. Joss. (2) "Uses of Small Motors" by G. M. Glendenning. (3) "X-Ray", Student Publication, by H. M. Duphorne. Attendance 76.

October 23, 1919. Papers: (1) "Industrial Relations" by R. G. Kloeffler. (2) "Cleaning of Blast Furnace Gases by Electrical Precipitation" by S. W. Honeywell. Attendance 72.

University of Kentucky.—October 30, 1919. Election of officers as follows—Chairman J. W. Coleman, Jr., Vice-chairman C. V. Garred, Secretary J. D. Wood, Treasurer N. T. Puckett.

University of Maine.—October 22, 1919, Hannibal Hamlin Hall. Address by Professor Barrows on the future and present fields of electrical engineering. Attendance 35.

Massachusetts Institute of Technology.—November 14, 1919. "X-Rays" by Dr. D. L. Webster. The lecture was illustrated by slides and experiments were performed with evacuated tubes showing conduction. Various interesting "toys" showing fluorescent effects were exhibited. Attendance 200.

Michigan Agricultural College.—November 6, 1919. Paper: "Automatic Telephones" by W. S. Bersey, a junior. Attendance 57.

School of Engineering of Milwaukee.—October 21, 1919. Organization meeting, at which John D. Ball was elected Chairman, J. L. Gordon Secretary, Henry Lowcock, Vice-Chairman and Merritt McCoy, Treasurer. Short talks on the purpose of the A. I. E. E. were given by Arthur Simon, Harrison Reed and Prof. F. A. Kartak. Attendance 122.

University of Missouri.—October 6, 1919, Engg. Bldg. Address by B. J. George on "Frequency Changers and their Parallel Operation". Attendance 20.

October 20, 1919, Engg. Bldg. Address by Mr. Sirian on "Improvements in Radio Communication." Attendance 25.

November 3, 1919. Paper: "Electric Furnaces" by B. J. Hungate. Attendance 13.

Montana State College.—October 15, 1919, Assembly Hall. Election of officers as follows—Chairman Jesse Flynn, and Secretary J. A. Thaler. Illustrated lecture by Dean Earl B. Norris on "Engineering Problems in Warfare." Attendance 58.

University of Nebraska.—October 15, 1919, Mechanical Engg. Bldg. Paper presented by Mr. J. B. Harvey, Vice-President of the Continental Gas and Electric Corporation on the qualities necessary for successful public utility work. Attendance 125.

University of North Carolina.—October 10, 1919, Chapel Hill. Election of officers as follows—Chairman W. W. Neal, Secretary M. E. Lake. Attendance 26.

October 17, 1919, Chapel Hill. Informal talks by Messrs. C. M. Hazelhurst, M. E. Lake, W. K. Harding, P. H. Daggett, J. E. Lear, I. H. Mustard, W. W. Neal. Attendance 72.

November 3, 1919, Chapel Hill. Introductory remarks on the advantages of electric ship propulsion by W. W. Neal, followed by the General Electric picture production "The Queen of the Waves." Attendance 202.

Ohio Northern University.—October 29, 1919, Dukes Memorial. Addresses: "Detail Testing" by Mr. Moses; "Variable Speed Generators" by Mr. Berry. Attendance 25.

Ohio State University.—October 29, 1919, Robinson Auditorium. Talk by Mr. C. P. Hoover, Columbus City Chemist, on the New Storage Dam and Water System, proposed for Columbus; and an illustrated talk on the method of water purification. Attendance 30.

November 12, 1919. Paper: "Automatic Reclosing Circuit Breakers" by Mr. Raney. Mr. Raney is a graduate of Ohio State and the inventor of the reclosing circuit breaker.

University of Pennsylvania.—November 6, 1919, Engineering Building. Papers: "Electric Arc Welding as a New Art", J. C. Carney; "House Wiring." P. Cooper. Attendance 52.

Stanford University.—October 23, 1919, Reorganization meeting, at which election of officers was held as follows: Chairman V. L. Tyndall, Secretary-Treasurer Hans O. Storm.

October 31, 1919, joint meeting with the Mechanical Engineering Society. Mr. Rathburn spoke on Arc Radio-Telegraphy with especial reference to the principles of the Poulsen Arc.

Syracuse University.—October 16, 1919. Address by Mr. Robert Jordan on "Electric Furnaces." The article was an original essay compiled from different references and experience. Attendance 11.

October 16, 1919. Address by E. P. Stewart on "Electrolysis." Attendance 14.

October 30, 1919. Address by Mr. Terry on "Telephone Transmission." The subject was taken from an article by Bancroft Gherardi in the *Telephone Engineer*. Attendance 12.

November 6, 1919. Address by Mr. Robert Jordan on "Electric Furnaces." Attendance 13.

November 13, 1919. Illustrated lecture by Mr. M. D. Low on "Alternators." Attendance 11.

Throop College of Technology.—November 6, 1919. Election of officers for college year 1919-1920, as follows: Chairman Russell M. Otis, Secretary Donald D. Smith.

Virginia Polytechnic Institute.—October 28, 1919. Lecture by Mr. Ray Smith on "The Electrification of the Norfolk and Western Railroads." Attendance 12.

University of Virginia.—October 21. 1919. Election of officers as follows, Chairman C. Henderson, Secretary W: W. Boyd. Program for the year discussed. Attendance 18.

November 6, 1919. Papers: "Graphic Recording Instruments;" "Structure of the Atom and its Position in Metals" by Professor Walter S. Rodman. Attendance 16.

Washington University.—October 22, 1919. Election of officers as follows: Honorary Chairman Prof. A. S. Langsdorf, Chairman Edward Bowles, Vice-Chairman Nick Skrainka, Secretary-Treasurer Fred W. Schramm. Attendance 21.

November 5, 1919. Meeting called for the purpose of instituting a membership campaign. Attendance 13.

ADDRESSES WANTED

Any reader knowing the present address of any of the following members is requested to communicate with the Secretary at 33 West 39th Street.

George H. Groce
(former address)
2857-59 S. Halstead St.,
McFell Signal Co.,
Chicago, Ill.

Ernest Kardos,
(former address)
156 E. 116th St.,
New York, N. Y.

A. B. McCollum,
(former address)
4030 Lindell Blvd.,
St. Louis, Mo.

Wm. A. Street,
(former address)
Gatun, C. Z.

ASSOCIATES ELECTED NOVEMBER 14, 1919

ALBRECHT, HARRY L., Meter Testing Dept., Commonwealth Edison Co., 28 No. Market St.; res., 837 No. Trumbull Ave., Chicago, Ill.

ANGELL, LAURENCE D., Sales Engineer, Ward Leonard Electric Company, Mt. Vernon; res., Douglaston, Long Island, N. Y.

ARFF, N., Electrical Inspector, Portland Railway, Light & Power Co.; res., 171 Green Ave., Portland, Ore.

AVANT, GEORGE G., Operating Engineer, Tide Water Power Co.; res., 418 South 2nd St., Wilmington, N. C.

*BARROWS, ARTHUR S., Inspector, Factory Insurance Association, Hartford, Conn.

BEAN, LESLIE P. R., State Supervising Engineer, Postmaster General's Dept., New South Wales, Aus.

BEASLEY, IRA EUGENE, The Newman Stern Co., Leader-News Bldg., Cleveland; res., 1417 Rockway Ave., Lakewood, Ohio.

BLAKELEY, GEORGE P. W., Electrical Engineer, N. Z. Refrigerating Co., Islington, N. Z.

BLAKEMORE, ERNEST, Engineer, Lancashire & Yorkshire Railway Loco Works; res., 31 Ramsbottom Road, Horwich, Lancashire, Eng.

BROOME, FRANK H., Laboratory Asst., Public Service Electric Co., Newark; res., 2684 Boulevard, Jersey City Heights, N. J.

BUTTON, HARRY W., Electrical Engineer, The American Railways Company, Witherspoon Bldg., Philadelphia; res., Narberth, Pa.

CAMPBELL, ARCHIBALD, Tester of Electrical Machinery, Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

CARRILLO, CARLOS MARIO, Electric Tester, Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., 309 Barnes St., Wilkinsburg, Pa.

CHADBOURNE, HENRY W., Power & Mining Engg. Dept., General Electric Co., Schenectady, N. Y.

*CLARK, EDWIN E., Instructor in Physics & Electrical Engineering, So. Dakota State School of Mines, Rapid City, So. Dakota.

CLAUSER, WILLIAM H., Sales Dept., Electric Storage Battery Co., 1823 L St., N.W., Washington, D. C.

COBB, FRED W., LIEUTENANT, U. S. Navy, Bureau of Supplies & Accounts, Navy Dept., Washington, D. C.

CONWELL, ALBERT L., Power House Foreman, Cerro de Pasco Copper Corp., Oroya, Peru, S. A.

CREAGER, PAUL S., Instructor, Electrical Engineering, Rutgers College, New Brunswick, N. J.

CRISWELL, WILLIAM G., District Clerk, Duquesne Light Co., Broad & Beatty Sts., E. E., Pittsburgh, Pa.

CROSWELL, DANIEL R., Manager of Operation, Cuyuna Range Power Co., Ironton, Minn.

CROY, HARRY C., Chief Draftsman, Distribution Engg. Dept., Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

DAWKINS, R. D., Load Dispatcher, Alabama Power Co., Birmingham, Ala.

DILLON, STEWART J., Master Mechanic, N. J. & S. R. R., Penn. R. R. Co., Camden, N. J.

DING, FRANK G., Salesman, Commercial Dept., Portland Railway, Light & Power Co.; res., 570 Fourth St., Portland, Ore.

DRIVER, HAROLD EDGAR, Asst. to District Manager, Westinghouse Elec. & Mfg. Co., 32 S. Peoria St., Chicago, Ill.

DUPONT, PIERRE LOUIS, Toll Equipment Supervisor, Cumberland Tel. & Tel. Co.; res., 2224 Marengo St., New Orleans, La.

FOOTE, WILLIAM W., Pearson Engineering Corp., 115 Broadway, New York, N. Y.

FOURNIER, DANIEL J., Galvanometer Testman, Michigan State Telephone Co., 185 Cass Ave., Detroit, Mich.

FUNDAMANT, WALLACE, Member, Southern Electric Works, 110 E. Freemason Street, Norfolk, Va.

*GLOVER, RAY PRICE, Telephone Engineer, American Tel. & Tel. Co., 1422 Hurt Bldg., Atlanta, Ga.

GROBE, JULIUS JOSEPH, Supt., Victor Electric Corp., 236 So. Robey St., Chicago, Ill.

HAMMEL, FRANK JOHN, Electrical Engineer, Forestall & Robison, 21 Park Row, New York, N. Y.

HANSEN, PETER B., Salesman, Northern Electric Co., 21 No. 6th St.; res., 4505 Washburn Ave. South, Minneapolis, Minn.

HOLLANDER, GEORGE J., Electrical Contractor, 143 W. 9th St., Erie, Pa.

HUMPHREY, ARTHUR LEE, Asst. Engineer, Tide Water Power Co., Wilmington, N. C.

HUSTON, FREDERICK P., Engineer, Metropolitan Edison Co., 16 So. 5th St., Reading, Pa.; res., Sweet Springs, Mo.

JACKSON, ROBERT A. F., Electrical Engineer, Motherwell Iron & Steel Co., Motherwell, Scotland.

JONES, HARRY EVAN, Telephone Engineer, Mountain States Telephone & Telegraph Co., Denver, Colo.

KAHAI, HARDEV SINGH, Asst. Elec. Engr., Sir William Beardmore & Co., Mossend Steel Works, Lanarkshire, Scotland.

KAHLER, GEORGE WILLIAM, Asst. Elec. Engineer, Schaw-Batcher Co. Ship Works, So. San Francisco; res., 628 Jackson St., Oakland, Cal.

KILPATRICK, JAMES GEORGE, Supervising Engineer, Commonwealth Public Service Co., Melbourne, Australia.

*KISHLAR, LAMAR M., Electrical Engineer, Wagner Electrical Mfg. Co., 6400 Plymouth Ave., St. Louis, Mo.

LEDERER, MELVIN E., Estimator & Electrical Draftsman, Harry Alexander, Inc., Munsey Bldg., Washington, D. C.

MARTIN, ALEXANDER, Electrical Engineer, 977 Multnomah St., Portland, Ore.

MASON, HENRY C., Electrician, J. G. White Engg. Corp., Nitrate No. 2, Muscle Shoals, Ala.

MATTHEWS, CHAS., Chief Electrician, Camp Curry, Yosemite Valley, Cal.

McPHAIL, HARVEY F., Chief Operator, U. S. Reclamation Service, Lingel, Wyoming.

McPHERSON, ROY BURDICK, Chief Load Dispatcher, Utica Gas & Electric Co., Utica; res., 547 Main St., New York Mills, N. Y.

NELSON, HENRY J., Electrician, U. S. Navy Yard. Bremerton; res., 125-15th Ave., Seattle, Wash.

PAINE, EDWARD ALLEN, Property Valuation & Engg. Work, Portland Railway, Light & Power Co., Electric Bldg., Portland, Ore.

PARISH, HAL LYNCH, Electrical Engineer, Durham Traction Company, Durham, N. C.

PARKER, JOHN ACTON, Draftsman, Niagara, Lockport & Ontario Power Company, 1638 Marine Trust Bldg., Buffalo, N. Y.

PARKER, William, Chief Electrician, Mercer Iron & Coal Co., Stoneboro, Penn.

*PAXSON, OLIVER H., JR., 1st Lieutenant, U. S. A., 2414 Bryn Mawr Ave., W. Philadelphia, Pa.

PETERSON, ARNOLD HERMAN, Ensign, U. S. N. R. F.; res., 7347 Princeton Ave., Chicago, Ill.

PFEIFER, WALTER S., District Manager, Allen-Bradley Co., 161 Devonshire St., Boston, Mass.

PIZZORNO, PETER P., Electrical Draftsman, The American Railways Co., Witherspoon Bldg., Philadelphia, Pa.

REQUENA, ENRIQUE G., Westinghouse Elec. & Mfg. Co., Newark, N. J.

ROGERS, FRED ARNOLD, Chief Electrician, Woonsocket Rubber Co.; res., 246 So. Main St., Woonsocket, R. I.

SCHADE, WILLIAM HENRY, Telephone Switchboard Engineer, Pacific Tel. & Tel. Co., 623 Sheldon Bldg., San Francisco, Cal.

SCHUHLER, ALBERT A., Elec. Instructor, David Rankin School of Mechanical Trades; res., 4700 Newberry Terrace, St. Louis, Mo.

SINCLAIR, CARROLL T., Asst. to Testing Engr., Pennsylvania Water & Power Co., Holtwood, Pa.

*__SCOTT, LEROY ELLSWORTH__, 2nd Lieut., U. S. A., Instructor, Signal School of Second Corps; res., 7 Mansfield St., New Haven, Conn.

SCOTT-TAGGART, JOHN, Head, Vacuum Tube Dept., Edison Swan Electric Co., 89 High St., Pondlers End, Middlesex, England.

SMALL, NATHAN B., Electrical Draftsman, with T. E. Murray, 124 East 15th St.; res., 833 East 167th St., New York, N. Y.

SMITH, HERRICK ANGELL, Automatic Chief, Western Union Telegraph Co.; res., 222 South 3rd St., Richmond, Va.

SPRARAGEN, LOUIS, Instructor in Elec. Engg. Dept., Sibley College, Cornell Univ.; res., Sheldon Court, Ithaca, N. Y.

STOWE, FRED FISHER, 1st Class Electrician, Navy Yard; res., 801 Allison St., N.W., Washington, D. C.

THORNTON, WILLIAM NELSON, Ensign, U. S. Navy, U. S. S. L-11, Norfolk, Va.

TIMMONS, JOHN S., Engineer & Supt., Callophone Co. of New York, 151 Grand St., New York; res., 604 Warburton Ave., Yonkers, N. Y.

TREAT, GUY BRADFORD, Chief Engineer & Asst. Manager, Oklahoma Railway Co., 213 Terminal Bldg., Oklahoma City, Okla.

TWITT, FRANK S., Elec. & Mech. Draftsman, McMyler Interstate Co.; res., 79 Columbus St., Bedford, Ohio.

*__WEIGT, JOHN W.__, Engineer, Electric Furnace Dept., John Thomson Press Co., 253 Broadway, New York; res., 107 Wilson Ave., Flushing, N. Y.

WILL, JAMES B., Lieut-Commander, U. S. N., Navy Yard, Boston, Mass.

WOESSNER, MATTHEW J., Lieut. (j.g.), U. S. Navy, Asst. Electrical Officer, U. S. Pennsylvania, New York, N. Y.

WOOD, HARRY LEE, Electrical Engineer, Stone & Webster Engineering Corp., 409 Electric Bldg., Seattle, Wash.

WOOD, JAMES E., District Manager, Roller-Smith Co., 711 Williamson Bldg.; res., 1931 E. 101st St., Cleveland, Ohio.

YOKOTA, TETSUJIRO, Westinghouse Elec. & Mfg. Co., Newark, N. J.

ZOOK, RICHARD M., Electrical Maintenance Dept., Western Electric Co., Hawthorne, Ill.

Total 80

*Former Enrolled Students.

ASSOCIATES RE-ELECTED NOVEMBER 14, 1919

FULLERTON, RUTHERFORD, Director, Kilbourne & Jacobs Mfg. Co., Columbus, Ohio.

LEUREY, LOUIS F., Consulting Electrical Engineer, Holbrook Bldg., 58 Sutter St., San Francisco, Cal.

MEMBERS ELECTED NOVEMBER 14, 1919

BAKER, IVAN F., Engineer, Westinghouse Electric International Co., 165 Broadway, New York, N. Y.; res., Mountain Lakes, N. J.

BROWN, HARRY L., Associate Editor, *Electric Railway Journal;* res., 555 W. 170th St., New York, N. Y.

CARR, SIDNEY T., Power Engineer, Central Hudson Gas & Electric Company, Poughkeepsie, N. Y.

FOSTER, E. G., Tramway Manager & Borough Electrical Engineer, Tramways & Electricity Dept., 19 Duke St., Invercargill, N. Z.

JEFFERSON, HERBERT FERRIER, Acting Chief Engineer, Kilbourne & Clark Mfg. Co., 3450 East Marginal Way, Seattle, Wash.

*__KEIL, RAYMOND H.__, Power Engineer, Jones & Laughlin Steel Co., 1001 B. F. Jones Bldg., Pittsburgh, Pa.

LAUPER, FRED A., Electrical Engineer & Designer, Empress Works; res., 43 Trinity St., Huddersfield, Eng.

McCLURE, J. HARVEY, General Supt., The Citizens Traction Co.; res., 810 West First St., Oil City, Pa.

Pillsbury, E. S., President, Century Electric Co., 1827 Pine St., St. Louis, Mo.

Quackenbush, Edward J., Chief Assistant Electrical Engineer, Havana Central Railroad Co., Havana, Cuba.

Rohman, Henry D., Chief Electrical Engineer, Stone-Franklin Company, 18 E. 41st St.; res., 884 Riverside Drive, New York, N. Y.

Sillcox, Lewis K., Master Car Builder, Chicago, Milwaukee & St. Paul R. R. System, W. Milwaukee Shops; res., 169-26th St., Milwaukee, Wis.

Smith, Robert Lewis, Factory Manager, Baxter D. Whitney & Son; res., 31 High St., Winchendon, Mass.

Smith, Roger Thomas, Electrical Engineer, Great Western Railway, 66 Porchester Road, London W. 2., England.

Stephenson, Ernest J., Chief Electrical Engineer, Lantaro Nitrate Co., Ltd., Taltal, Chile, S. A.

Whitsit, Lyle A., Clarendon, Va.

FELLOW ELECTED NOVEMBER 14, 1919

Crowley, Henry J., General Manager, The American Railways Co., 1321 Walnut St., Philadelphia, Pa.

TRANSFERRED TO THE GRADE OF MEMBER NOVEMBER 14, 1919

Arana, Victor M., Consulting Electrical Engineer, Head of Electrical Dept., National School of Arts and Crafts, Lima, Peru, S. A.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its regular monthly meeting, held on November 3, 1919, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

Alexander, Harry, Electrical and Mechanical Engineer, New York, N. Y.

Alexanderson, E. F. W., Consulting Engineer, General Electric Co., Schenectady, N. Y.

To Grade of Member

Burnham, Roy R., Consulting Engineer Boston, Mass.

Corney, Chester A., Electrical Engineer, Stone & Webster, Boston, Mass.

Dillon, Theodore H., Professor of Electrical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

Eldredge, Mark, Engineer, Ludlow Mfg. Associates, Ludlow, Mass.

Howe, William M., First Lieut., Corps of Engineers, U. S. Army, Washington, D. C.

Namba, Masashi, Professor of Electrical Engineering, Imperial University, Kioto, Japan.

Nikiforoff, Basil, Electrical Engineer, Operating Dept., Alabama Power Co., Birmingham, Ala.

Robison, Arch, Assistant Construction Supt., J. G. White Engineering Corp., Muscle Shoals, Ala.

Schmid, Ernest E., Vice-President and Manager, Shield Electric Co., New York, N. Y.

Wood, Frank W., Vice-President and Chief Engineer, Chas. Cory & Son, Inc., New York, N. Y.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before December 31, 1919.

Anthony, H. M., Muncie, Ind.
Arnold, J. C., Seattle, Wash.
Ashbrook, R. B., San Gabriel, Cal.
Askue, A. R., Cleveland, Ohio.
Beiswenger, O. L., Akron, Ohio

Birk, J. W., Annapolis, Md.
Bishop, J., Toronto, Ont.
Bitner, R. E., New York, N. Y.
Bowen, W. C., Pittsburgh, Pa.
Bozzi, M. T., New Haven, Conn.
Braff, J., New York, N. Y.
Brill, A. T., Annapolis, Md.
Creager, E. F., (Member), Anderson, Ind.
Crouchley, F. D., Ft. Wayne, Ind.
Dagnall, C. H., Ithaca, N. Y.
Dietze, E., New York, N. Y.
Dionne, J. A., Montreal, P. Q.
Dixon, J. E., Chicago, Ill.
Duren, G. M., St. Louis, Mo.
Ellis, H. W., Cleveland, Ohio
Evans, D. G., Kenosha, Wis.
Fairman, J. F., Ann Arbor, Mich.
Fay, L. W., St. Louis, Mo.
Fisher, J. C., Baltimore, Md.
Fowler, W. K., Jr., Schenectady, N. Y.
Fox, H. N., Montour Falls, N. Y.
Gannett, D. K., New York, N. Y.
Gettlin, A. A., Burlington, N. J.
Goodwin, G. L., Port Clinton, Ohio
Grigsby, L. C., St. Louis, Mo.
Haas, J. S., Atlantic City, N. J.
Hancock, M. S., E. Pittsburgh, Pa.
Hansen, B. A., (Member), New York, N. Y.
Hemenway, E. G., Hampton Roads, Va.
Herskowitz, L., New York, N. Y.
Hinkle, A. E., Pittsfield, Mass.
Horle, L. C. F., (Member), Washington, D. C.
Hotchkiss, G. ,Brooklyn, N. Y.
Hunt, R., (Member), Wilmington, N. C.
Huth, H. R., Milwaukee, Wis.
Hyde, L. H., Ft. Wayne, Ind.
Jaeger, G. A., Jr., New York, N. Y.
Kahant, C. G., New York, N. Y.
Karker, E. C., Rochester, N. Y.
Kelly, J. R., New York, N. Y.
Kindall, E. N., Harrisburg, Pa.
Kiso, D., E. Pittsburgh, Pa.
Kongsted, L. P., Pittsburgh, Pa.
Lea, E., Schenectady, N. Y.
Lee, A. W. H., New York, N. Y.
Leung, N. H., Cambridge, Mass.
Lockwood, J. B., Lockport, N. Y.
Mac Rae, F.G., New York, N. Y.
Marsteller, G. F., Nanticoke, Pa.
Meade, T. R., Seattle, Wash.
Miller, F. R., Schenectady, N. Y.
Morlan, S. E., Denver, Colo.
McKean, H. S., Toronto, Ont.
Newton, E. G., Sand Springs, Okla.
Norton, J. E., Roxbury, Mass.
Nott, G. E., Toronto, Ont.
Olsen, O. M., Washington, Ind.
Pendarvis, H. R., Chicago, Ill.
Petzing, E. W., Chicago, Ill.
Philips, R. C., Toronto, Ont.
Pinckney, G. M., New York, N. Y.
Randall, L. C., Brooklyn, N. Y.
Reagan, M. E., Kansas City, Mo.
Riley, H. J., New York, N. Y.
Roberts, W. van B., Princeton, N. J.
Rosenauer, M. B., Dorchester, Mass.
Rukenbrod, J. K., E. Pittsburgh, Pa.
Russell, M. H., Schenectady, N. Y.
Seely, G. T., (Member), Chicago, Ill.
Shepard, J. A., (Member), Montour Falls, N. Y.
Sherman, H. S., St. Louis, Mo.
Shetzline, R. A., New York, N. Y.
Short, P. B., Pittsburgh, Pa.
Singer, S. B., St. Louis, Mo.
Smith, H. G., Schenectady, N. Y.
Smith, P. C., Pittsburgh, Pa.
Subers, C. V. A., Ashbourne, Pa.
Swanson, E. S., Chicago, Ill.
Tahnage, C. H., Salt Lake City, Utah
Tessohn, I. M., New York, N. Y.
Therkelsen, E., Bozeman, Mont.
Thrall, E. F., New Haven, Conn.
Towle, N. L., E. Pittsburgh, Pa.
Umpleby, G. F., Baltimore, Md.
Van Meter, R. H., Niagara Falls, N. Y.
Ward, H. C., Rochester, N. Y.
Wegmann, C. A., Canton, Ohio
Werden, E. T., New York, N. Y.
Wheeler, H. H., New York, N. Y.
Whitney, A. J., New York, N. Y.
Whittman, F. E., Toronto, Ont.
Woolston, L. F., St. Louis, Mo.
Wright, E. M., San Francisco, Cal.

Total 99.

Foreign Applications

Anciaux, L., (Member), Arequipa, Peru
Caudrelier, E., (Member), Paris, France
Edgcumbe, K.,(Member),London, Eng.
MacNelley, C. J., Balboa, C. Z.

Mercier, E. F. H., (Member), Paris France
Mundy, S. G., Edinburg, Scotland.
Nash, G. H., (Fellow), London, Eng.
Total 7.

STUDENTS ENROLLED NOVEMBER 14, 1919

10478 Baxter, R. H., Missouri State Univ.
10479 Hane, W. S., N. Y. Elec. School
10480 Orr, R. C., Jr., Penn. State Coll.
10481 Scholz, E. G. O., N. Y. Elec. School
10482 Eshelman, W. S., Penn. State Coll.
10483 Moeslein, E. D. W., Penn. State Coll.
10484 Barber, J. L., A.&M. Coll. of Tex.
10485 Stewart, C. E., Univ. of Wash.
10486 Miller, LeR. V., Stevens Inst. of Tech.
10487 Hollister, G. E., Purdue Univ.
10488 Hume, C. D., Purdue Univ.
10489 Whitford, R. A., Purdue Univ.
10490 Harvey, H., Purdue Univ.
10491 Hartley, T. K., Purdue Univ.
10492 Gotschall, P. H., Purdue Univ.
10493 Vaile, H. S., Purdue Univ.
10494 Garver, A. O., Purdue Univ.
10495 Elder, M. E., Ohio No. Univ.
10496 Barrett, W. J., Brooklyn Poly. Inst.
10497 Erdman, E. A., Ohio No. Univ.
10498 Starrett, J. S., Brooklyn Poly. Inst.
10499 Bowles, E. L., Washington Univ.
10500 Rosenberg, T. LeC., Univ. of Cal.
10501 Robbins, C. W., Univ. of Cal.
10502 King, C. S., Univ. of Cal.
10503 Hansen, E. B., Univ. of Cal.
10504 Scheer, G. B., Univ. of Cal.
10505 McIntire, M. M., Univ. of Cal.
10506 Woodruff, E. T., Univ. of Cal.
10507 Pressley, J. H., Univ. of Cal.
10508 Wilhelmi, R. B., Univ. of Cal.
10509 Beaty, W. H., Univ. of Cal.
10510 Wood, T. A., Univ. of Cal.
10511 Boerner, L. F., Univ. of Cal.
10512 Holm, H. F., Univ. of Cal.
10513 Meyer, H. B., Univ. of Cal.
10514 Wehle, A. H., Brooklyn, Poly. Inst.
10515 Kelsey, H. D., Syracuse Univ.
10516 Cole, K. J., Syracuse Univ.
10517 Greiner, R. E., Syracuse Univ.
10518 Hayford, B. I., Syracuse Univ.
10519 Langan, J. A., Syracuse Univ.
10520 Low M. D., Syracuse Univ.
10521 Quinlan, T. F., Syracuse Univ.
10522 Schroeder, A. C., Syracuse Univ.
10523 Stewart, E. P., Syracuse Univ.
10524 Terry, G. W., Syracuse Univ.
10525 Swam, R. E. S., Penn. State Coll.
10526 Snow, H. B., Cornell Univ.
10527 Race, H. H., Cornell Univ.
10528 Knox, R. S., Kansas State Agr. Coll.
10529 Honeywell, S. W., Kansas State Agr. Coll.
10530 Lucas, M. J., Kansas State Agr. Coll.
10531 Simmons, G. H., Univ. of Ill.
10533 Knox, A. D., Sheffield Scientific School
10534 Misrach, J. S., Univ. of Ky.
10535 Nisbet, K. R., Univ. of Ky.
10536 Bailey, J. H., Univ. of Ky.
10537 Choate, D. C., Univ. of Ky.
10538 Garred, U. V., Univ. of Ky.
10539 Park, R. S., Univ. of Ky.
10540 Coleman, J. W., Jr., Univ. of Ky.
10541 Gordon, C. W., Univ. of Ky.
10542 Hargraves, C. M., Univ. of Ky.
10543 McClure, C. R., Univ. of Ky.
10544 Wood, J. D., Univ. of Ky.
10545 Puckett, N. T., Univ. of Ky.
10546 Waterfill, R. W., Univ. of Ky.
10547 Boone, H. P., Univ. of Ky.
10548 Marrs, W. C., Kansas State Agr. Coll.
10549 Zimmerman, C. L., Kansas State Agr. Coll.
10550 Hilliard, R. D., Kansas State Agr. Coll.
10551 Randolph, G. L. F., Univ of Ill.
10552 Wright, H. L., Univ. of Ill.
10553 Winchel, P. B., Kansas State Agr. Coll.
10554 Morris, C. F., Kansas State Agr. Coll.
10555 Storey, T. G., Kansas State Agr. Coll.
10556 La Mont, J. E., Kansas State Agr. Coll.
10557 Berg, L. R., Univ. of Wash.

10558 Williams, S. E., Univ. of Ill.
10559 Doyle, F. B., Univ. of Ill.
10560 Metzger, H. A., Cornell Univ.
10561 Tennygold, K., Cornell Univ.
10562 McClure, D. F., Cornell Univ.
10563 Molinet, E., Cornell Univ.
10564 Spencer, R. V., Univ. of Wash.
10565 Bebb, E. L., Kansas State Agr. Coll.
10566 Amsden, B. R., Worcester Poly, Inst.
10567 Jemmett, D. M., Mass. Inst. of Tech.
10568 Smith, F. H., Univ. of Ill.
10569 Wenzel, W. L., Univ. of Notre Dame
10570 Rosenthal, G. D., Washington Univ.
10571 Meador, B. F., Washington Univ
10572 Watts, W. R., Washington Univ.
10573 Briner, H. F., Washington Univ.
10574 Tripodi, D., Washington Univ.
10575 Lewis, W., Washington Univ.
10576 Maupin, R. L., Jr., Washington Univ.
10577 Bosworth, H. R., Univ. of Ill.
10578 Baukson, R. L., Washington Univ.
10579 Skrainka, R. M., Washington Univ.
10580 Suransky, P., Univ. of Wash.
10581 Mathison, D., Brooklyn, Poly. Inst.
10582 Haug, A. J., Univ. of Wash.
10583 Axman, E., Univ. of Wash.
10584 Burrough, E. L., Univ. of Wash.
10585 Luft, E. W., Univ. of Wash.
10586 Maney, W. L., Univ. of Wash.
10587 Heacock, W. J., Univ. of Wash.
10588 McCandless, C. H., Kansas State Agr. Coll.
10589 Huether, J. J., Univ. of Notre Dame
10590 Duphorne, M., Kansas State Agr. Coll.
10591 Deghuee, R. P., Stevens Inst. of Tech.
10592 Murphy, M. F., Univ. of Wash.
10593 Rice, A., Univ. of Wis.
10594 Anderson, N. M., Univ. of Cal.
10595 Mott, E. V., Penn. State Coll.
10596 Shaw, A. E., Brooklyn Poly. Inst.
10597 Michell, H. G., Univ. of Manitoba.
10598 Fellows, H. A., Michigan Agr. Coll.
10599 Kinney, R. C., Michigan Agr. Coll.
10600 Rann, M. B., Michigan Agr. Coll.
10601 Lankton, G. E., Michigan Agr. Coll.
10602 Rayner, R. L., Michigan Agr. Coll.
10603 Keely, L. F., Michigan Agr. Coll.
10604 Jacobs, F. S., Michigan Agr. Coll.
10605 Heasley, R. M., Michigan Agr. Coll.
10606 Stelzer, J. G., Michigan Agr. Coll.
10607 Davidson, J. B., Michigan Agr. Coll.
10608 Sumarlidason, F., Univ. of Wash.
10609 Salley, J. D., Clemson Agr. Coll.
10610 Schroeder, J. H., Clemson Agr. Coll.
10611 Abernathy, W. H., Clemson Agr. Coll.
10612 Sarratt, R. C., Jr., Clemson Agr. Coll.
10613 Ricker, G. F., Clemson Agr. Coll.
10614 Graves, C. C., Clemson Agr. Coll.
10615 Leigler, T. J., Clemson Agr. Coll.
10616 Yougul, C., Clemson Agr. Coll.
10617 Epps, A. R., Clemson Agr. Coll.
10618 Mace, S. N., Clemson Agr. Coll.
10619 Gower, A. G., Jr., Clemson Agr. Coll.
10620 DuRant, C. O., Clemson Agr. Coll.
10621 Lachieott, L. H., Clemson Agr. Coll.
10622 Refo, H. C., Clemson Agr. Coll.
10623 Childs, L. H., Clemson Agr. Coll.
10624 Watkins, W. W., Clemson Agr. Coll.
10625 Riley, G. M., Jr., Clemson Agr. Coll.
10626 Givner, S., Clemson Agr. Coll.
10627 Haas, C. I., Clemson, Agr Coll.
10628 Hoffmeyer, H. F. C., Jr., Clemson Agr. Coll.
10629 Cullum, U. X., Clemson Agr. Coll.
10630 Tyler, C. L., Clemson Agr. Coll.
10631 Kempson, J. M., Clemson Agr. Coll.

10632 Shedd, R. L., Clemson Agr. Coll.
10633 Banks, W. D., Clemson Agr. Coll.
10634 Leland, R. E., Clemson Agr. Coll.
10635 Rentz, N. G., Clemson Agr. Coll.
10636 Cobb, C. C., Clemson Agr. Coll.
10637 Fowler, W. W., Clemson Agr. Coll.
10638 Blume, W. E., Casino Tech, Night School
10639 Weiss, L., N. Y. Elec. School
10640 Parsons, R. J., Casino Tech. Night School
10641 Horton, L. V., Yale Univ.
10642 Hubbell, F. J., Yale Univ.
10643 Hallabaugh, S. E., Jr., Univ. of Ark.
10644 Hart, R. P., Univ. of Ark.
10645 Gardner, O. D., Kansas State Agr. Coll.
10646 Breese, R. S., Kansas State Agr. Coll.
10647 Hirata, M., Univ. of Neb.
10648 Minnich, C. T., Univ. of Neb.
10649 Strom, A. P., Univ. of Neb.
10650 Corson, LeR., N. Y. Elec. School
10651 Jickling, R. W., Univ. of Manitoba
10652 Boesen, P. J., Univ. of Ill.
10653 Clark, W. C., Univ. of Okla.
10654 Creel, W. H., Univ. of Okla.
10655 Gilbert, M. G., Univ. of Okla.
10656 Harris, F. K., Univ. of Okla.
10657 Howell, J. O., Univ. of Okla.
10658 Huckaby, F. F., Univ. of Okla.
10659 Humphrey, J. E., Univ. of Okla.
10660 Lewis, A. L., Univ. of Okla.
10661 McLane, C. L., Univ. of Okla.
10662 McQuown, K. C., Univ. of Okla.
10663 Nonweile, O. C., Univ. of Okla.
10664 Pendleton, O. A., Univ. of Okla.
10665 Pendleton, V. A., Univ. of Okla.
10666 Ross, M. C., Univ. of Okla.
10667 Swaze, J. E., Univ. of Okla.
10668 Wallace, A. McM., Univ. of Okla.
10669 Wann, G. S., Univ. of Okla.
10670 Wells, J. L., Univ. of Okla.

Total 191

OFFICERS AND BOARD OF DIRECTORS 1919-1920

President

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PROCEEDINGS

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

INDEX TO VOLUME XXXVIII

JANUARY 1, TO DECEMBER 31, 1919

INDEX TO SUBJECTS

Page

Abnormal Voltages within Transformers, (L. F. Blume and A. Boyajian)................*February*, 211

Absolute Measurement of the Intensity of Sound, The, (A. G. Webster)................*July*, 889

Aeronautics in the United States, 1918, (George O. Squier), *February*, 53

Airplane Antenna Constants,................*November*, 390

Aldred Lectures on Engineering Practise,................*April*, 130

American Engineering Standards Association,................*June*, 213

American Engineering Standards Committee, Statement Regarding Reorganization,................*July*, 260

American Engineering Research, (*W. R. Whitney*)......*February*, 115

American Engineers go to France, ...*January*, 4

American Meteorological Society, Formation of........*December*, 423

An Appeal to the Membership of the Institute,..........*February*, 74

Annual Meeting—Edison Medal Presentation,...*May*, 163; *June*, 206

Annual Meeting of Society for Promotion of Engineering Education,................*June*, 206

Annual Reports of Technical Committees,................*July*, 901

Applicability of Automatic Switching to all Classes of Telephone Service, (A. B. Smith)................*December*, 1335

Applications for Election, *January*, 9; *February*, 68; *March*, 112; *April*, 149; *May*, 187; *June*, 232; *July*, 288; *August* 307; *September*, 317; *October*, 367; *November*, 408; *December*, 439

A. S. C. E. Meeting,................*November*, 377

Associates Elected, *January*, 6; *February*, 64; *March*, 104; *April*, 143; *May*, 178; *June*, 225; *July*, 275; *September*, 318; *November*, 401; *December*, 436

Associates Reelected, *January*, 8; *February*, 67; *March*, 111; *April*, 148; *May*, 186; *June*, 231; *July*, 287; *November*, 406; *December*, 438

Atoms in Metals, Positions of, (A. W. Hull)................*October*, 1171

Bill to Establish a Federal Department of Public Works,....*July*, 257

Broad Scientific Research Program Advocated by American Federation of Labor,................*July*, 263

Cable, The Dielectric Field in an Electric Power, (R. W. Atkinson) *June*, 815

Cable for Polyphase Systems, High-Tension Single-Conductor, (W. S. Clark and G. B. Shanklin)................*June*, 663

California 220,000-Volt—1100 Mile—1,500,000 Kw. Transmission Buss, (R. W. Sorensen, H. H. Cox and G. E. Armstrong), *September*, 1027

Carnegie, Andrew,................*September*, 314

Classification and Compensation of Engineers,................*July*, 258

Classification and Compensation of Railroad Engineers,.....*May*, 168

Conference on Commercial and Engineering Training,.......*July*, 262

Conventions,
  Annual, ... *May*, 164; *June*, 203; *July*, 247
  Midwinter .... *January*, 1; *February*, 55; *March*, 91
  Pacific Coast, ... *June*, 205; *August*, 297; *September*, 311
Cooperation (President's Address) (C. A. Adams) .... *July*, 877
Correction of Error in 1918 Edition of National Electrical Code, *July*, 263
Delegates to France Report to Societies, ... *March*, 94
Development of the Institute, ... *July*, 253; *September*, 331
Dielectric Field in an Electric Power Cable, The, (R. W. Atkinson) *June*, 815
Dielectric Strength of Air Films Entrapped in Solid Insulation and A Practical Application of the Problems for Alternator Coils and Cables, (F. Dubsky) .... *February*, 141
Dielectrics, The Effect of Transient Voltages on, (F. W. Peek, Jr.) *June*, 717
Dismissal of Public Service Commission Engineers in New York City, ... *March*, 100
Edison Medal Presentation—Annual Meeting, ... *May*, 163; *June*, 207
Effect of Transient Voltages on Dielectrics II, The, (F. W. Peek, Jr.) *June*, 717
Election of Officers of Illuminating Engineering Society, ... *July*, 264
Electric Circuits, III, General Equations, The, (C. P. Steinmetz) *March*, 249
Electric Power Generation in Ontario on Systems of Hydroelectric Power Commission (Arthur H. Hull) .... *January*, 29
Electromagnetic Induction, Report on, (S. J. Barnett) ..... *October* 1151
Electromagnetic Theory of the Telephone Receiver, (A. E. Kennelly and H. Nukiyama) .... *April*, 491
Employment Service, ... *January*, 13
Engineer as a Citizen, ... *May*, 173
Engineering and Industrial Standardization, (C. A. Adams) *April*, 549
Engineering Council Announcement by National Service Committee, ... *May*, 166
Engineering Council—A New Member Society .... *February*, 61
Engineering Council—Extracts from Annual Report for Year Ending Feb. 20, 1919, ... *April*, 134
Engineering Council Reports, *August*, 298; *September*, 316; *October*, 359; *November*, 383; *December*, 419
Engineering Foundation—Abstract of Annual Report for Year Ending February 20, 1919, ... *April*, 132
Engineering Service Bulletin, *January*, 14; *February*, 74; *March*, 119; *April*, 154; *May*, 194; *June*, 219; *July*, 268; *August*, 300; *September*, 325; *October*, 362; *November*, 391; *December*, 423
Engineering Societies Library, *January*, 18; *February*, 78; *March*, 123; *April*, 158; *May*, 198; *June*, 223; *July*, 273; *August*, 304; *September*, 328; *October*, 365; *November*, 397; *December*, 428
Engineering Societies to Assist the Joint Employment Service of Federal State and Civic Bodies, ... *June*, 215
Engineering Standards Conferences in France and England, .. *June*, 212
Engineers Corps Under the Proposed Army Reorganization, *September*, 314
Exhibit of Army Personnel Work, ... *April*, 130
Fellows Elected *January*, 8; *July*, 288; *September*, 322; *December*, 439
Field of Activity of Engineering Council, ... *January*, 4
Fifth National Exhibition of Chemical Industries, *June*, 206; *August*, 297
Fusion in Arc Welding, (O. H. Eschholz) .... *March*, 319
Future A. I. E. E. Meetings, *February*, 57; *March*, 86; *April*, 127; *July*, 256; *August*, 297; *November*, 377; *December*, 411
General Equations of the Electric Circuits III (C. P. Steinmetz) *March*, 249
Grounded Neutral Transmission Line, (W. E. Richards) .. *August*, 1005
Grounding the Neutral of Generating and Transmission Systems, (H. R. Woodrow) .... *June*, 745

High-Tension Single-Conductor Cable for Polyphase Systems, (W. S. Clark and G. B. Shanklin)........................*June,* 663
Honor Roll,...*January,* 21
Hydroelectric Power Commission, Electric Power Generation in Ontario on Systems of, (Arthur H. Hull).............*January,* 29
I. E. C. Meeting, London, October 20-24..............*November,* 382
Industrial Relations,................................*November,* 390
Industrial Safety Codes..............................*December,* 422
Inherent Limitations on Transformations Possible by Stationary Apparatus, (Joseph Slepian).......................*September,* 1061
Institute of Radio Engineers,...........................*March,* 100
Insulation, Ionization of Occluded Gases in High-Tension, (G. B. Shanklin and J. J. Matson)........................*February,* 163
Insulators, Suspension, Theory of Probabilities Applied to Failure of, (L. M. Klauber)...................................*August,* 959
Ionization of Occluded Gases in High-Tension Insulation (G. B. Shanklin and J. J. Matson)........................*February,* 163
John Fritz Medal for General Goethals, Awarded by Engineering Societies,............................*February,* 61; *June,* 214
Joint Meeting in India,.................................*March,* 92
Joint Meeting in New York, October 1,................*November,* 378
June Meeting of Institute of Radio Engineers,..............*June,* 206
Lighting Codes, Present Status of Industrial, (G. H. Stickney) *April,* 611
Meetings,
  A. I. E. E. Regular,
  Philadelphia, December 13, 1918,..................*January,* 3
  New York, January 10, 1919..........*January,* 1; *February,* 57
  Boston, March 14,........................*March,* 85; *April,* 129
  New York, April 11, 1919.................*April,* 127; *May,* 164
  New York, Joint A. I. E. E. and I. R. E. October 1,..*October,* 355
  Philadelphia, October 10, 1919, *September,* 311; *October,* 355; *November,* 378
  New York, November 14,..........*November,* 377; *December,* 412
  New York, December 12,..........................*December,* 411
  Branches, *February,* 64; *March,* 103; *April,* 142; *May,* 176; *June,* 218; *July,* 266; *November,* 381; *December,* 433
  Directors, *January,* 2; *February,* 58; *May,* 164; *June,* 210; *July,* 255; *September,* 313; *November,* 380; *December,* 413
  Sections, *January,* 5; *February,* 63; *March,* 86; 101; *April,* 140; *May,* 174; *June,* 216; *July,* 265; *August,* 299; *October,* 356; *November,* 381; *December,* 432
Meetings of Radio Engineers,..*April,* 128; *May,* 165; *November,* 378
Members Elected, *January,* 8; *February,* 67; *March,* 111; *April,* 148; *May,* 186; *June,* 231; *July,* 287; *September,* 322; *November,* 406; *December,* 438
Method of Financing Sections,..........................*November,* 380
Motor Transport Training Schools of the Army ......*November,* 390
National Conference on Commercial and Engineering Training, *June,* 206
National Drainage Congress,..........................*November,* 378
National Motor Truck Show and Highway Transport Conference..*December,* 418
National Research Council,...........................*February,* 62
National Research Fellowships in Physics and Chemistry,...*July,* 264
National Safety Council,.............*September,* 313; *November,* 390
Naval Radio Stations for Commercial Use,...............*October,* 358
New Appointments at Massachusetts Institute of Technology, *September,* 315
Nominations for Institute Officers for 1919–1920........*January,* 2
Nominations for Institute Officers for 1920–21..........*December,* 417
Obituary, *January,* 12; *February,* 73; *April,* 154; *May,* 192; *June,* 237; *July,* 292; *August,* 308; *October,* 367; *November,* 401; *December,* 431

Order and Amplitude of Harmonics in Voltage Wave Forms with Indicating Instruments, (Leslis F. Curtis).............. *August*, 947

Personal, *January*, 12; *February*, 76; *March*, 118; *April*, 153; *May*, 192; *June*, 235; *July*, 291; *August*, 308; *September*, 324; *October*, 367; *November*, 400; *December*, 432

Philadelphia Meeting of American Chemical Society,.. *September*, 312

Piezo Electric Effect in the Composite Rochelle Salt Crystal, (A. McL. Nicolson)...................................... *November*, 1315

Plans of A. I. E. E. Committee on Development.......... *March*, 86

Positions of Atoms in Metals, The, (A. W. Hull)......... *October*, 1171

Power Plants in Parallel, Some Problems in the Operation of, (E. C. Stone).. *August*, 973

Power Resources of North Atlantic States,................ *May*, 174

Predetermination of Synchronous Phase-Modifier Performance, (Hubert V. Carpenter).............................. *August*, 997

Present Limits of Speed and Output of Single-Shaft Turbo Generators, (F. D. Newbury)............................ *November*, 1233

Present Limits of Speed and Power of Single Shaft Curtis Steam Turbines, (Eskil Berg)............................. *November*, 1223

Present Limits of Speed and Power of Single-Shaft Steam Turbines, (J. F. Johnson)................................... *November*, 1243

Present Status of Industrial Lighting Codes (G. H. Stickney) *April*, 611

President, Letter from............................ *December*, 414

Principles of Radio Transmission and Reception with Antenna and Coil Aerials, (J. H. Dellinger)......................... *October*, 1095

Principles Underlying Radio Communication.............. *May*, 174

Problems of 220-kv. Power Transmission, (A. E. Silver).... *June*, 751

Radio Communication, Transatlantic,.................. *October*, 1077

Radio Telephony, (E. B. Craft and E. H. Colpitts)....... *March*, 337

Radio Transmission and Reception with Antenna and Coil Aerials, Principles of, (J. H. Dellinger).................... *October*, 1095

Railroad Electrification, Some Possibilities of, as Affecting Future Policies, (Calvert Townley).......................... *April*, 541

Reactance Coils, Some New Formulas for, (H. B. Dwight) *September*, 1039

Recommended for Transfer, *January*, 9; *February*, 68; *March*, 112; *April*, 149; *May*, 186; *June*, 231; *July*, 288; *August*, 308; *September*, 324; *November*, 407; *December*, 439

Relay Protection, Transmission Line, (H. R. Woodrow, D. W. Roper, O. C. Traver, P. MacGahan).................. *June*, 631

Report of Board of Directors,............................ *June*, 857

Report of Boards Committee on Technical Activities.... *December*, 414

Report of Committee of Tellers on Nomination Ballots,.... *April*, 128

Report of Committee of Tellers on Election of Officers,..... *June*, 212

Report of Delegates to France to Founder Societies,.... *September*, 317

Report of Joint Conference Committee of the Development Committee,.. *November*, 413

Report of Patent Committee to the National Research Council, *February*, 62

Report of Special Committee on Publications.......... *November*, 410

Report on Electromagnetic Induction, (S. J. Barnett).... *October*, 1151

Research, American Engineering, (W. R. Whitney)..... *February*, 115

Research in Alloys, Cooperative........................ *December*, 413

Research in America After the War, (R. A. Millikan)... *February*, 129

Reunion of Eighty-Niners,............................ *May*, 165

Review of Work of Sub-Committee on Wave Shape Standard of the Standards Committee, (H. S. Osborne)........... *January*, 1

Scientific and Technical Employees of the Government in Washington Organized,.................................. *June*, 214

Searchlight in the U. S. Navy, The (R. Kelly)......... *December*, 1369

Smith-Howard Bill,.................................... *May*, 170

Some New Formulas for Reactance Coils, (H. B. Dwight) *September*, 1039

Some Possibilities of Steam Railroad Electrification as Affecting Future Policies, (Calvert Townley).................... *April*, 541

Some Problems in the Operation of Power Plants in Parallel, (E. C. Stone)........*August*, 973
Spring Meeting of A. S. M. E........*June*, 205
Standardization as an Aid to World Peace,........*October*, 356
Standardization, Engineering and Industrial, (C. A. Adams).*April*, 549
Standardization of Technical Symbols,........*February*, 63
Students Enrolled, *January*, 11; *February*, 70; *March*, 115; *April*, 152; *May*, 190; *June*, 234; *July*, 290; *September*, 324; *November*, 408; *December*, 441
Technical Books Including A. I. E. E. Transactions Wanted for University of Louvain,........*December*, 418
Technical Men for the Consular Service,........*October*, 358
Telephone Circuits with Zero Mutual Induction (W. W. Crawford) *March*, 377
Telephone Interference Factor, Collection of Data on...*February*, 59
Telephone Receiver, Electromagnetic Theory of the, (A. E. Kennelly and H. Nukiyama)........*April*, 491
Telephone Repeaters, (B. Gherardi and F. B. Jewett)...*November*, 1255
Theory of Probabilities Applied to Failure of Suspension Insulators, (L. M. Klauber)........*August*, 959
Theory of the Transient Oscillations of Electrical Networks and Transmission Systems (John R. Carson)........*March*, 407
Transatlantic Radio Communication, (E. F. W. Alexanderson) *October*, 1077
Transferred to Grade of Member, *January*, 8; *February* 67; *March*, 112; *April*, 149; *May*, 186; *June*, 231; *July*, 288; *September*, 323; *November*, 407; *December*, 439
Transferred to Grade of Fellow, *January*, 8; *February*, 68; *March*, 112; *April*, 149; *May*, 186; *July*, 288; *September*, 323; *November*, 407
Transformations Possible by Stationary Apparatus, Inherent Limitations on, (Joseph Slepian)........*September*, 1061
Transformers, Abnormal Voltages Within, (L. F. Blume and A. Boyajian)........*February*, 211
Transmission Bus, California 220,000 Volt—1100 Mile—1,500,000 Kw., (R. W. Sorensen, H. H. Cox, and G. E. Armstrong) *September*, 1027
Transmission Line, Grounded Neutral, (W. E. Richards) *August*, 1005
Transmission Line Relay Protection, (H. R. Woodrow, D. W. Roper, O. C. Traver, and P. MacGahan)........*June*, 631
Turbo Generators, Single Shaft, Present Limits of speed and Output of, (F. D. Newbury)........*November*, 1233
Turbines, Steam, Present Limits of Speed and Power of Single-Shaft Curtis, (Eskil Berg)........*November*, 1223
Turbines, Steam, Single-Shaft, Present Limits of Speed and Power of, (J. F. Johnson)........*November*, 1243
United Engineering Society—Extracts from Treasurers Annual Report for Year Ending December 31, 1918........*April*, 131
United Engineering Societies Library Report,........*April*, 138
Utilizing the Time Characteristics of Alternating Current, (Henry E. Warren)........*May*, 629
Vacuum Tube as a Generator of Alternating-Current Power, The (John H. Morecroft and H. Trap Friis)........*October*, 1193
Vail Library at M. I. T........*November*, 382
Vocational Training for Crippled Soldiers, Sailors and Marines, *July*, 263
Wave Shape Standard, of the Standards Committee, Review of Work of Sub-Committee on (H. S. Osborne)........*January*, 1
Weaver Memorial Tablet,........*June*, 207
Welding as a Process in Ship Construction, (S. V. Goodall).*March*, 329
Welding, Fusion in Arc, (O. H. Eschholz)........*March*, 319
Welding Mild Steel, (H. M. Hobart)........*April*, 561
Year Book 1919........*February*, 59

INDEX OF AUTHORS

Adams, C. A., *April*, 549; *July*, 877
Alexanderson, E. F. W., *October*, 1077
Armstrong, G. E., *September*, 1027
Atkinson R. W., *June*, 815
Barnett, S. J., *October*, 1151
Berg, Eskil, *November*, 1223
Blume, L. F., *February*, 211
Boyajian, A., *February*, 211
Carpenter, Hubert V., *August*, 997
Carson, John R., *March*, 407
Clark, W. S., *June*, 663
Colpitts, E. H., *March*, 337
Cox, H. H., *September*, 1027
Craft, E. B., *March*, 337
Crawford, William W., *March*, 377
Curtis, Leslie F., *August*, 947
Dellinger, J. H., *October*, 1095
Dubsky, F., *February*, 141
Dwight, H. B., *September*, 1039
Eschholz, O. H., *March*, 319
Friis, H. Trap, *October*, 1193
Gherardi, Bancroft, *November*, 1255
Goodall, S. V., *March*, 329
Hobart, H. M., *April*, 561
Hull, Arthur H., *January*, 29
Hull, A. W., *October*, 1171
Jewett, Frank B., *November*, 1255
Johnson, J. F., *November*, 1243
Kelly, R., *December*, 1369
Kennelly, A. E., *April*, 491
Klauber, L. M., *August*, 959
MacGahan, P., *June*, 631
Matson, J. J., *February*, 163
Millikan, R. A., *February*, 129
Moreeroft, J. H., *October*, 1193
Newbury, F. D., *November*, 1233
Nicolson, A. McL., *November*, 1315
Nukiyama, H., *April*, 491
Osborne, Harold S., *January*, 1
Peek, F. W., Jr., *June*, 717
Richards, W. E., *August*, 1005
Roper, D. W., *June*, 631
Shanklin, G. B., *February*, 163
Shanklin, G. B., *June*, 663
Silver, A. E., *June*, 751
Slepian, Joseph, *September*, 1061
Smith, A. B., *December*, 1335
Sorensen, R. W., *September*, 1027
Squier, George O., *February*, 53
Steinmetz, Charles P., *March*, 249
Stickney, G. H., *April*, 611
Stone, E. C., *August*, 973
Townley, Calvert, *April*, 541
Traver, O. C., *June*, 631
Warren, Henry E., *May*, 629
Webster, A. G., *July*, 889
Whitney, W. R., *February*, 115
Woodrow, H. R., *June*, 631, 745

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REVIEW OF WORK OF SUB-COMMITTEE ON WAVE SHAPE STANDARD OF THE STANDARDS COMMITTEE*

BY HAROLD S. OSBORNE

ABSTRACT OF PAPER

The paper gives a review of the work done during the past three years by a sub-committee of the Standards Committee of the Institute appointed to make recommendations for changes in the Institute's rules regarding the wave shape of alternators. After a very careful consideration of the question and a large amount of experimental work the Sub-Committee last spring made recommendations that for the present the ten per cent deviation rule should be retained without change (except in wording), and that trial use should be made of a supplementary wave shape factor. The new factor, based on the relation between voltage wave shape and interfering effect in telephone circuits, when power and telephone lines parallel each other, is called the "telephone interference factor." The committee invites the broadest discussion and trial use of the new factor. No attempt will be made to decide upon limiting values of the factor until after wide experience shall have been obtained in its use, and the committee will welcome assistance on the part of any interested in collecting information to this end.

THIS paper is presented at the request of the sub-committee on Wave Shape Standard to encourage "the trial use of telephone interference factor and the collection of information by any who are interested."

Introduction. Until the past year the only standard of wave-shape included in standardization rules of the American Institute of Electrical Engineers has been the rule that the maximum deviation from the equivalent sine wave should not exceed 10 per cent of the amplitude of the equivalent sine wave. This provision has been in the standardization rules for many years and has done excellent service in preventing the use of machines having grossly distorted wave-shapes.

On a number of occasions papers and discussions have been presented to the Institute criticising the 10 per cent deviation

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*The author acknowledges the assistance of the other members of the Sub-Committee on Wave Shape Standard. The members of this Sub-committee are: C. A. Adams, Frederick Bedell, L. W. Chubb, A. W. Copley, F. M. Farmer, H. S. Osborne, L. T. Robinson and A. E. Silver.

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rule. In two papers presented to the Institute in 1913 (*Wave-Form Distortions and Their Effects on Electrical Apparatus,* by P. M. Lincoln, and *Proposed Wave-Shape Standard,* by C. M. Davis) it was pointed out that the deviation standard has two marked disadvantages in that it sets approximately the same limit for harmonics of all frequencies and is relatively difficult of application.

The discussion of these papers has led to the consideration of wave-shape factors other than the deviation and of more convenient means for determining them. The simplest method so far suggested of determining a wave factor is by devising an electrical network such that the current in one branch resulting from a complex voltage wave at the terminals of the network is an indication of the distortion of the voltage wave in question. The harmonics of the wave may be given a desired relative weighting by using a suitable network.

The wave-shape standard proposed by Mr. Davis in the paper cited above employed for its determination the simplest form of such a network. He suggested that the weighting of the harmonics be proportional to their frequency, and that this weighting be obtained by using as a measure of wave shape the ratio of the admittance of a condenser to the complex wave to the admittance of the condenser to a sine wave of the same frequency. The factor so measured is called the differential distortion factor. This and several other means of measuring wave shape were discussed again before the Institute in 1915 (*Distortion Factors,* by Professor Bedell). The attention which had been directed to the subject led in December, 1915, to the appointment by the Standards Committee of a sub-committee to consider this subject and make recommendations.

Outline of the Work of the Sub-committee. The form of wave-shape standard which was suggested by Mr. Davis has a number of characteristics which recommend it. In the form suggested, however, it would be exceedingly difficult of practical application, largely because of errors in measurement caused by the inductance and resistance of the machines under test and of the measuring instrument. The committee first turned its attention to the possibility of developing a satisfactory standard by simple modifications of that proposed by Mr. Davis formed by adding a series resistance or a resistance and inductance to the condenser which is the measuring circuit in that standard. It was hoped that a satisfactory standard of this sort could be developed that would be so simple that it could be set up from standard coils, condensers and meters available in any well equipped laboratory.

The different methods of measuring wave shape, which under these limitations could be given serious consideration, are discussed in a paper presented to the Institute in 1916 by Professor Bedell reporting the progress of the sub-committee's work (TRANSACTIONS, 1916, page 1154). However, it was the conclusion of the sub-committee, based on a large amount of experimental work,—that whatever form of network might be adopted it would need to be set up as a special piece of apparatus with the constants carefully specified. It was also found necessary to use with the apparatus a highly sensitive indicating instrument, such as a vacuum thermocouple with a direct current milliammeter or a very sensitive alternating-current dynamometer milliammeter. Moreover, a network of any of the forms discussed in the progress report was felt to be not entirely satisfactory because the readings obtained would not vary rapidly with changes in wave shape and also because the relative penalizing of different harmonics was arbitrarily determined by the constants of the network.

These conclusions led the committee to consider the development of a rating of wave shape or wave-shape factor, unrestricted by the requirement of a simple series arrangement of measuring network, which would give as accurately as practicable a measure of the detrimental effect of any wave, taking into account effects on power systems and inductive effects on communication circuits. To such a factor the harmonics of different frequencies would contribute both in proportion to their magnitude and in proportion to the amount of the disturbance which they would individually cause if of the same magnitude.

The committee has found that but very little definite information is available regarding the relative effect of harmonics of different frequencies on the operation of power systems. For the present any modification of the 10 per cent deviation standard for the purpose of weighting the harmonics with reference to their effect on the operation of power systems would have to be based on general judgment and does not seem to be necessary.

On the other hand when telephone systems come within the inductive influence of power systems more trouble has been experienced, and this trouble bears a definite relation to the frequencies of the harmonics in the wave form. Consequently the committee has collected definite experimental data regarding the relative effect of harmonics of different frequencies in producing interference in telephone systems.

In view of these facts, the committee has proposed as a first step in a revision of the rules regarding wave shape and pending the obtaining of further information, that the present deviation factor be retained for all alternators and that an additional factor be adopted to be applied to alternators which will be used on open-wire * transmission and distribution systems. This additional factor is based entirely on the effect of the harmonics in producing interference in telephone circuits when the power and telephone circuits are parallel. In accordance with this conclusion the sub-committee has developed, and the Standards Committee has adopted for trial use, a new wave-shape factor which is called the telephone-interference factor. No attempt has been made to set values of the telephone-interference factor which should be used as limits, it being considered important that a large amount of data and experience be obtained before values are set. The purpose of this paper is to call attention to the new factor, to tell how it was obtained and to describe in detail the apparatus by which it may be measured so that any one interested can assist the committee in obtaining experience with the use of the new factor and in determining what would be the best limiting values of the factor to be adopted as standard.

New Standardization Rules. In the new standardization rules regarding wave-shape the old rule for maximum deviation remains unchanged except in the wording. The new rules are as follows:

Section 17 (new)

The deviation factor of a wave is the ratio of the maximum difference between corresponding ordinates of the wave and of the equivalent sine wave of equal length to the maximum ordinate of the equivalent sine wave when the waves are superposed in such a way as to make this maximum difference as small as possible. (See Section 406)

Section 406 (new)

A deviation factor, as defined in Section 17, of the terminal voltage wave on open-circuit of all synchronous machinery not exceeding 10 per cent is permissible except when otherwise specified.

The new factor, called a telephone-interference factor, is covered by new sections in the Standards' rules, reading as follows:

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*By open-wire system is meant one which is not in cable.

Section 17 A (new)

The interference factor of a wave is a measure of its departure from the sinusoidal shape based upon its disturbing effects when acting by induction on other circuits. (See Sections 407 and 408).

Section 407 (new)

The telephone interference factor is the ratio of the square root of the sum of the squares of the weighted values of all the sine-wave components (including in alternating waves both fundamental and harmonics) to the r.m.s. value of the wave.

Section 408 (new) (*For trial only*)

The weighting of the sine-wave components of different frequencies is as given in the following curve. (Fig. 1). The telephone interference factor of a voltage wave, corresponding to this weighting, may be measured by the use of the network shown in the following diagram (Fig. 2). With this network the telephone interference factor is the ratio of the current *I* in micro-amperes in the meter branch of the network to the voltage *E* applied to the external terminals of the network. The measurement may be made on the low tension side of a potential transformer. A sensitive vacuum thermo-couple provided with a shunt, and a direct-current milliammeter have been found convenient for measuring the current.

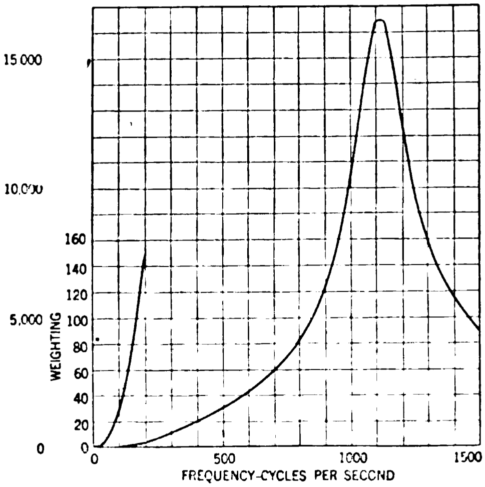

Fig. 1—Frequency-Weighting Curve for Interference Wave Factor

Section 409 (new)

A telephone interference factor (See Sections 17A and 407) of the open-circuit terminal voltage wave not exceeding * . . . is permissible except when otherwise specified. This rule shall apply in cases where synchronous machinery is required for use in connection with open-wire transmission or distribution circuits and shall be supplementary to 406. The purchaser shall in each case indicate whether or not the conditions are such that this section applies.

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*The appropriate limiting value of this factor has not yet been determined, but will be recommended after further experience shall have been obtained.

Relation Between Wave Shape and Telephone Interference. The great importance of the harmonics in voltage and current waves of the power system in determining how much interference the power circuit will cause in parallel telephone circuits is well illustrated by the curve given in Rule 408. This curve represents the relative amount of interference caused by voltages of the same magnitude but different frequencies in the power circuit. From the curve it is estimated that at 1100 cycles the interference per volt is approximately 9000 times that at 60 cycles and 60,000 times that at 25 cycles.

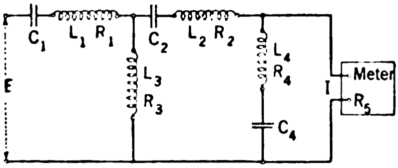

FIG. 2—NETWORK FOR MEASUREMENT OF INTERFERENCE WAVE FACTOR

NETWORK CONSTANTS.

$C_1 = 0.9$ mf.	± 0.5%	$L_1 = 0.023$ henry	± 0.5%	$R_1 = 5$ ohms ± 2%
$C_2 = 0.9$ "		$L_2 = 0.0205$ "		$R_2 = 12$ " ± 2%
		$L_3 = 0.068$ "		$R_3 = 73$ " ± 1%
$C_4 = 7.5$ "		$L_4 = 0.019$ "		$R_4 = 22.5$ " ± 2%
				$R_5 = 43$ " ± 1%

This means that if the harmonics were entirely absent from a 25-or 60-cycle power system, the problem of inductive interference from the system with telephone service would practically vanish. Although this condition cannot, of course, be obtained, anything which causes an approach to it causes a reduction in the amount of interference under conditions otherwise the same and therefore makes possible a reduction in the expense which is necessary in the plants of the power and telephone systems in order to avoid excessive interference. There is therefore a direct economic advantage from the standpoint of present day conditions in designing and building alternators with as low a telephone interference factor as practicable; provided no material increase in cost is involved.

Determination of the Relative Importance of Frequencies in Telephone Interference. The curve given in new Rule 408 has been developed to represent the variation with frequency of the amount of interference in parallel telephone circuits from a given voltage applied to the power circuit, other conditions being the same. It is based on experimental work carried out under the direction of the chairman of the Sub-committee and which is described in Appendix A. The methods by which these results were obtained may be briefly summarized as follows:

Two methods have been used. In each case known amounts of current of different frequencies have been inserted in the telephone receiver of an ordinary telephone circuit, using for convenience artificial lines. With one method the observers listened to the reading of ordinary news matter over the noisy circuit and then over a quiet circuit of greater length and indicated over which circuit they could understand better. This method, is of course, crude if the results of a single observer be considered and the results obtained by different observers vary widely. However, averaging the results obtained in large numbers of observations the results obtained in two distinct sets of tests check closely. The two sets of tests were made four years apart, with different observers and under somewhat different conditions, and the check of the results obtained indicates strongly that the method is sound.

The second method is based on articulation tests. With this method the goodness of transmission over the telephone circuit is measured by the percentage of syllables spoken over the circuit which are correctly apprehended by the listener. The syllables are arranged in groups which are so selected that each group represents ordinary speech both in the relative number and in the arrangement of the fundamental sounds of which speech is composed. Therefore, the percentage of correctly received syllables is a measure of the degree of intelligibility of the conversations held over the circuit. The percentage of words correctly understood in an actual conversation is, of course, very much higher than that obtained in the articulation tests because the syllables used in the test are without context and, in general, without meaning. The articulation tests made in connection with this experimental work involve 60,000 observations, considering each syllable as an observation.

The articulation tests do not necessarily give a measure of the complete detrimental effect of the noise caused by extraneous currents because in addition to the reduction of intelligibility in the telephone circuit, there is a factor of annoyance to the person using the telephone. It is interesting to note that the relative results obtained by the articulation tests check those obtained by the reading tests for low frequencies, and then with frequencies above 1000 cycles, show progressively less effect. This indicated that the reading tests include in part the factor of annoyance which becomes relatively more important with the high frequencies.

The experimental work which is briefly discussed above gives a curve representing in relative terms the combined effect of varying sensitiveness of the telephone receiver and of the human ear. The shape of the curve depends much, of course, on the constants of the receiver. The receiver used in this work, however, was typical in this respect of all receivers in general use in the country and the curve represents a relation between sensitiveness and frequency of current which will probably be approximately maintained for a number of years.

In developing from this experimental work a curve to be made the basis of a new wave-shape factor, consideration has been given to other elements which help to determine the relative amount of noise caused by generator voltages and currents of different frequencies. The more important of these are outlined below:

a. The current induced in telephone circuits by a given voltage or current in the power circuit is approximately proportional to the frequency. This effect was taken into account in determining the weighting curve.

b. The attenuation of the harmonic components of the current as they are propagated along the power and telephone circuits varies with the frequency. Except in rare instances, this effect is small compared with the others which are taken into account. It was therefore omitted.

c. In some forms of telephone apparatus, there may be appreciable selective action tending to change the relative amount of currents of different frequencies which reach the receiver. Loaded telephone lines generally do not transmit currents above about 2500 cycles, but the effect of these currents is normally inappreciable in the production of noise because of their almost complete absence from the power system. Some forms of telephone apparatus tend to eliminate the currents of low frequencies. These currents have a very small effect on the amount of noise, however, except when present in very large volume. In general, the condition for a good telephone apparatus requires that it transmit with approximately equal efficiency all frequencies important in the reproduction of speech and it is just these frequencies which are important in the production of noise from extraneous sources. The effect of the apparatus is therefore in general small compared with the other factors which have been included and this effect has been neglected in determining the weighting curve.

In accordance with (a) the curve which is presented in Rule 408 was obtained by multiplying the experimental curve of relative interference of currents of different frequencies by a factor proportional to the frequency. As a result of the experimental work which has been done and of the above considerations the committee believes that the curve selected is the best curve for use at this time.

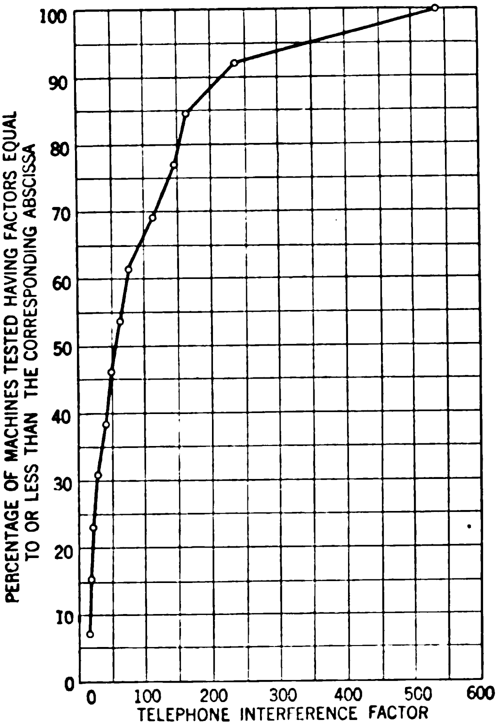

Fig. 3

Description of Apparatus and Method of Use. In order to make the use of the new telephone interference factor a simple matter, the committee has developed apparatus in which the ratio of current through one branch of a network to the voltage applied at its terminals gives a measure of the telephone inter-

TABLE I

RESULTS OF MEASUREMENTS WITH NETWORK

Number	Frequency	Number phase	Volts	Kv-a.	Rev. per min.	Type	Telephone interference factor determined by network	Oscillogram
1	25	3	2,200	6,000	1,500	G	**5**	
2	60	3	13,200	12,500	1,800	G	**11**	
3	60	3	600	450	138.5	G	**11**	
4	60	2	2,300	2,500	3,600	G	**11**	
5	60	3	13,200	12,500	1,800	G	**12**	
6	60	3	2,300	3,750	3,600	G	**13**	
7	25	3	440	800	136.3	G	**14**	
8	60	3	2,200	925	120	G	**14**	
9	60	3	13,200	25,000	1,800	G	**16**	
10	60	2	2,300	35	1,800	G	**16**	
11	60	3	600	1,250	164	G	**16**	
12	60	3	6,500	6,250	375	G	**16**	**38**
13	60	2	2,600	3,000	600	G	**17**	
14	60	2	2,400	2,500	1,800	G	**18**	
15	....	3	2,300	30	1,800	G	**18**	
16	60	2	2,400	2,500	1,800	G	**18**	
17	25	3	2,300	50	750	G	**18**	
18	60	3	13,200	2,350	3,600	G	**18**	
19	60	2	2,200	180	514	M	**18**	
20	25	3	2,200	625	500	M	**19**	
21	30	3	2,200	450	300	M	**19**	
22	25	3	6,600	1,440*	500	M	**19**	**9**
23	60	2	2,400	625	3,600	G	**19**	
24	60	3	13,200	25,000	1,800	G	**20**	
25	60	2	2,300	850	....	G	**20**	
26	25	3	13,200	9,000	750	G	**20**	
27	60	2	2,300	850	90	G	**21**	
28	60	3	2,300	300	1,200	M	**22**	
29	25	3	2,200	290*	750	M	**23**	
30	60	3	2,200	625	250	M	**23**	
31	25	3	13,200	1,800	94	G	**24**	
32	60	3	13,200	9,000	1,800	G	**25**	
33	60	3	2,200	6,000	300	M	**25**	
34	25	3	13,200	1,800	94	G	**26**	
35	60	3	600	750	1,200	C	**26**	
36	60	3	13,200	5,000	1,800	G	**27**	
37	60	1	1,100	187	1,200	G	**27**	
38	60	3	2,300	935	3,600	G	**29**	
39	60	2	2,500	500	400	G	**30**	
40	60	2	2,200	6,000	....	G	**30**	**30**
41	60	3	2,300	3,750	300	M	**32**	
42	60	3	250	1,000	600	C	**34**	**35**
43	60	2	2,600	750	90	G	**34**	
44	60	2	2,400	1,500	1,800	G	**35**	
45	60	3	7,000	500	100	G	**35**	
46	60	3	250	1,000	600	C	**36**	**30**
47	60	2	2,300	850	90	G	**37**	
48	60	3	600	450	150	G	**38**	
49	25	3	390	3,500	300	M	**38**	
50	50	3	480	400	1,000	C	**42**	**31**
51	60	3	6,600	2,500	3,600	G	**42**	
52	60	3	2,300	100	900	G	**44**	
53	60	2	2,300	1,000	1,800	G	**46**	
54	60	2	2,300	1,000	1,800	G	**46**	
55	60	3	2,200	625	250	M	**46**	
56	60	3	2,300	150	600	G	48	

TABLE I (*Continued*)

RESULTS OF MEASUREMENTS WITH NETWORK

Number	Frequency	Number phase	Volts	Kv-a.	Rev. per min.	Type	Telephone interference factor determined by network	Oscillogram
57	60	3	240	94	600	G	50	72
58	60	2	2,300	1,000	1,800	G	50	
59	25	3	13,200	5,000	500	G	50	
60	25	3	250	750	750	C	50	
61	60	3	250	300	1,200	C	51	68
62	60	3	250	500	1,200	C	51	23
63	60	3	250	500	1,200	C	51	
64	60	3	250	500	1,200	C	54	54
65	60	3	250	500	1,200	C	54	
66	60	3	250	500	1,200	C	60	
67	60	3	2,300	540	150	G	60	
68	60	3	2,300	50	1,200	G	61	
69	60	3	250	500	1,200	C	61	55
70	60	3	240	500	1,200	C	64	83
71	60	3	250	500	1,200	C	64	
72	60	3	2,300	300	450	G	66	
73	60	3	2,300	500	400	G	66	
74	60	3	3,810	500	720	G	67	54
75	60	3	2,300	150	225	G	67	
76	60	3	240	94	600	G	69	75
77	60	3	1,200	500	1,200	C	70	86
78	60	3	2,400	437	300	G	72	
79	60	1	1,150	30	1,500	G	75	
80	60	3	1,000	50	1,200	G	77	
81	60	....	13,200	20,000	720	G	78	
82	60	3	250	300	1,200	C	80	75
83	60	3	2,200	445*	900	M	83	
84	60	3	250	200	1,200	C	85	106
85	50	3	220	320	187.5	G	92	
86	50	3	2,200	580	750	G	105	
87	60	3	2,300	75	600	G	110	
88	60	3	2,200	225	900	M	111	
89	60	....	13,200	10,000	720	G	113	
90	60	3	600	800	180	G	113	100
91	50	3	5,250	625	....	G	122	139
92	60	3	220	75	77	G	132	140
93	60	3	2,300	1,000	300	G	136	
94	60	3	2,200	4,000	....	G	....	138
95	60	3	13,200	3,000	600	G	140	
96	62.5	3	2,200	2,000	....	G	....	142
97	60	3	250	500	1,200	C	145	57
98	60	3	2,200	225*	900	M	146	146
99	60	3	2,300	325	720	M	147	
100	60	3	2,200	4,000	....	G	....	147
101	60	3	6,600	1,080*	514	M	148	
102	60	3	2,200	225*	900	M	149	177
103	60	3	2,200	225*	900	M	152	
104	60	3	2,200	290*	900	M	153	195
105	60	3	2,200	225*	900	M	155	137
106	60	3	2,200	225*	900	M	156	175
107	60	3	2,200	290*	900	M	160	
108	60	3	2,200	435*	900	M	163	164
109	60	3	2,200	225*	900	M	164	151
110	60	3	2,200	225*	900	M	165	166
111	60	3	2,200	250	300	M	180	

TABLE I (*Continued*)
RESULTS OF MEASUREMENTS WITH NETWORK

Number	Frequency	Number phase	Volts	Kv-a.	Rev. per min.	Type	Telephone interference factor determined by network	Oscillogram
112	60	3	2,200	290*	900	M	181	189
113	60	3	13,200	3,000	720	G	190	
114	60	3	2,200	290*	900	M	191	171
115	60	3	2,200	750	300	M	193	
116	60	3	2,300	1,000	277	G	200	
117	60	3	2,200	225*	900	M	201	139
118	60	3	2,200	225*	900	M	207	221
119	60	3	2,300	300	450	G	230	
120	60	3	240	150	225	G	239	228
121	60	3	480	400	200	G	262	
122	60	3	240	33	1,200	G	299	
123	60	1	1,150	50	1,200	G	305	
124	60	3	600	75	900	G	352	
125	60	3	13,200	1,000	1,200	G	360	
126	60	3	2,200	210*	257	M	375	375
127	60	3	13,200	1,000	1,200	G	430	
128	25	3	11,000	500	1,500	G	450	
129	60	....	13,200	9,000	720	G	490	
130	60	2	1,150	50	900	G	543	

Types of Machine:
G = Generator
M = Synchronous Motor
C = Synchronous Converter
*Rating given in Horse Power.

ference factor. The essential electrical constants of the network are given in the diagram in Rule 406. A detailed description and specification of the apparatus is given in Appendix B to this paper.

The measuring instrument of the apparatus consists of a vacuum thermocouple connected to a direct-current milli-ammeter. When there are a number of harmonics in the voltage wave applied to the apparatus, this instrument gives a reading proportional to the square root of the sum of the squares of the effects of the individual harmonics. The data which have been obtained regarding the law of combination of the detrimental effects of a number of sources of noise disturbance in a telephone circuit, indicate that this law varies under different extreme conditions. It seems probable that the root-sum-square law best represents the average condition and it is far more practicable for use than any other law because of the characteristics of measuring instruments. It has therefore been adopted.

Summary of Results Obtained with Network. The sub-committee has used this network for measurements of the wave-factor of the open-circuit voltage of a considerable number of machines. Some of the results which have been obtained are given in Table I—Results of Measurements with Network. These results are summarized in the curve of Fig. 3.

In the last column of Table I are given the results obtained in the case of the machines in checking the reading of the network by computing the telephone interference factor from the analysis of oscillograms. In order to obtain this check it is necessary to carry the analysis out to the 25th harmonic, and in some cases higher, in order to include the tooth harmonics. These analyses have shown that the use of the network involves not only much less work but also gives greater accuracy than the computation of the factors from the analysis of the oscillograms.

Approximate analyses which were made in a number of cases show very clearly that in general the machines with high telephone interference factors are machines with large slot harmonics. It is evident that this should be so from the shape of the admittance curve of the network. This is illustrated by the following table which gives the relative amounts of harmonics of different orders which would give the same value of telephone interference factor assuming that one harmonic only in addition to the fundamental is present in the wave.

Harmonic	Approximate relative amount
3	100
5	26.7
7	10.4
9	6.6
11	4.4
13	3.0
15	1.86
17	..96
19	.73
21	1.25
23	1.90
25	2.57

Determination of Limiting Values. The question of what limiting values of telephone-interference factor should be adopted for the construction of new machinery will, of course, be an economic one. There will be a point beyond which further reduction in the telephone-interference factor of machines, would involve an increase in cost greater than would be warranted by the damage caused or greater than the cost of outside-plant methods of obtaining equally effective results. It is proposed by the sub-committee not to recommend any limiting values for use until adequate data shall have been obtained. In the meanwhile, the sub-committee wishes to enlist the cooperation of any who are interested in the work of gathering as much information as possible which can contribute to the result Practicability in application seems to require that the measurements of telephone-interference factor be made with the machines operating on open-circuit. Load on a generator modifies the wave-form and results obtained indicate that in general, the telephone-interference factor of the voltage wave of the power system is less than the no-load factor of the worst machine connected to it.

The sub-committee is particularly anxious to get from the operating engineers data regarding the relation between the telephone-interference factor of the system voltage under the usual load conditions and the factors of the individual generators and motors connected to it, as measured on open circuit. Valuable information can thus be obtained by measuring the wave factors of the generators and other important pieces of rotating machinery on open-circuit and at rated speed, and recording also the measurements of resultant interference factor on the system at regular intervals, and as far as it can be determined, the load conditions of all generators at the time the measurements are made and other conditions on the system which would affect the results. The data submitted should, when possible, include the following information regarding individual machines:

1. Telephone interference factor.
2. Complete name plate data and name of manufacturer.
3. Terminal voltage at time of measurement.
4. Speed at time of measurement.
5. Load condition at time of measurement.

Attention is particularly called to the fact that in many cases the telephone-interference factor varies rapidly with the speed. The speed should therefore be carefully controlled and should be as accurately measured as possible.

The members of the sub-committee will be pleased to hear from anyone who is willing to cooperate in this work, and to supply any desired information regarding apparatus and methods.

Future Work. Future work will involve the collection of the information necessary for recommendations regarding the limiting values of telephone-interference factor to be applied to new alternating current rotating apparatus. Such values should not be recommended until a large amount of information shall have been obtained and full opportunity given all interested to acquaint themselves with the new factor and to offer comments. Furthermore, the application of the new rules should be so timed that manufacturers will not be inconvenienced in adjusting themselves to them. Future work should include also the collection of any available information regarding the effect of different harmonics on the operation of power systems in order that the desirability of modifying the present deviation factor may be reviewed.

In the present rules, the deviation factor and the telephone interference factor are applied only to synchronous machinery. A complete consideration of the subject would require a study of the effect of other classes of electrical machinery upon the wave forms of the currents and voltages of the systems to which they are connected.

APPENDIX A

RELATIVE INTERFERING EFFECTS OF SINGLE-FREQUENCY CURRENTS IN THE TELEPHONE RECEIVER

The frequency-weighting curve for the telephone-interference factor (Fig. 1) is based upon several experimental investigations to determine the relative interfering effect of single-frequency currents in a telephone receiver. These investigations were conducted at different times, and by different methods, by the Engineering Department of the American Telephone and Telegraph Company. The general principles of the different methods are given in the body of the paper. Details of procedure and data are given in this appendix.

"Reading" Tests of 1914. In the first series of tests* a typical telephone circuit was set up, using artificial cable, and arranged so that different single-frequency currents could be separately introduced in the telephone receiver at the listening end of the circuit, simultaneously with the normal telephone current. By throwing a switch the listener could remove the disturbing current from the circuit and at the same time reduce the volume of sound output from the receiver, the amount of this reduction and the amount of the disturbing current being set by the reader or caller and being unknown to the listener.

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*Made in 1914 at the request of the (California) Joint Committee on Inductive Interference.

The procedure was for the caller to read over the circuit while the listener switched from the noisy condition to the quiet condition and the reverse, until the latter made his judgment as to which of the two circuits would be preferable for carrying on a conversation. This judgment was signaled to the caller, who then changed the amount of volume-reduction or the noise and the procedure was repeated. By this means, and after an average of about five different settings of reduction in volume, the listener's opinion as to what reduction equaled in effect the given amount of single-frequency disturbing current was indicated. In these tests frequencies of 60, 180, 400, 800, and 1500 cycles were used. Four strengths of disturbing current of each frequency were employed, with an average of eight observers. This involved a total of 160 determinations, each of which was based on an average of five separate judgments, making a total of 800 judgments. The results obtained in these tests indicated a linear relationship between the amount of disturbing current and the volume reduction expressed in terms of miles of cable added to the standard testing circuit. The relative interfering effects of equal currents of the different frequencies employed in these tests are shown by the points marked "X" in Fig. 4.

"Reading" Tests of 1918. The tests made in 1914 were not considered final and in 1918 they were supplemented by further studies. In these latter tests it was felt that particular regard should be paid to 1100 cycles because the resonance point of telephone receivers is in the neighborhood of this frequency. The circuit was arranged, by using an amplifier, so that receivers for a number of observers were connected to the same circuit simultaneously while someone at the calling end switched from the noisy condition to the quiet condition with reduced volume, or the reverse, every 15 seconds. After some experimenting, it was found satisfactory to have the caller read for a total of 2 minutes, thus giving four periods of 15 seconds each for each condition. At the end of this time each observer recorded his judgment as to the relative desirability of the two conditions. For each frequency of interfering current, similar comparisons were made with two callers and for five reductions in volume on the quiet circuit. In this series of tests the comparisons were made for frequencies of 180, 400, 800, 1100, and 1500 cycles with from 8 to 11 observers, involving in all over 1000 judgments. For three of these

frequencies more than one value of current was used but for the other two only one value was used. As the previous tests established a linear relationship between current strength and reduction in volume expressed in miles of standard cable, the data could all be reduced to loss per unit current. The results obtained in this series of tests, together with those obtained in 1914, are represented by curve *A* of Fig. 4. It should be noted that for the frequencies common to the two series of tests, namely 180, 400, 800, and 1500 cyles, the results check very closely.*

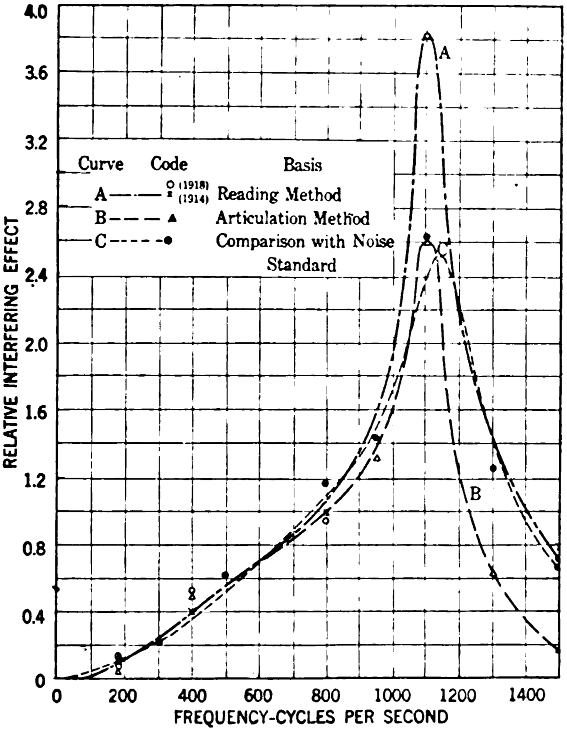

FIG. 4—RELATIVE INTERFERING EFFECT OF SINGLE FREQUENCY CURRENTS IN A TELEPHONE RECEIVER

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*The preliminary results obtained in 1914 have been presented to the Institute in the form of a curve (TRANSACTIONS, Vol. 34, page 1182, Fig. 4, Curve *C*). Within the precision of the data, this tentative curve agrees with the curve given here below 800 cycles, but is quite different in the range, between 800 and 1500 cycles, in which no observations had been made in the 1914 tests.

"Articulation" Tests. These tests were made by having a caller at the transmitting end of a typical telephone circuit speak into the transmitter lists of syllables which were phonetically balanced in groups of 50, while a number of observers, with receivers connected to the receiving end of the circuit through an amplifier, recorded the sounds which they heard. A comparison of these records with the lists of sounds called shows the percentage of syllables correctly received, and this is taken as the measure of the articulation for the condition of the circuit at the time. Articulation measurements of this sort were made with different single-frequency disturbing currents in the receivers at the listening end of the circuit and also without these disturbing currents but with conditions otherwise the same. Tests of this nature were made for values of disturbing currents of the following frequencies: 180, 400, 800, 950, 1100, 1300, 1500 and 1700 cycles. Two callers and five observers were employed. Using the percentage articulation over the quiet circuit as the basis of reference, the effects of the disturbing currents are expressed as the differences in the percentage articulation for the noisy and quiet circuits. The ratio of these differences for equal values of disturbing currents then gives a measure of the relative effects of currents of different frequencies. Curve *B* of Fig. 4 is a plot of these results.

With the articulation method, tests were made for two different lengths of circuit which gave a variation in the telephone energy delivered to the receivers at the listening end in the ratio of approximately 9:1. The results obtained with the two lengths of circuit varied in their absolute values, but the relative effect of different frequencies was practically the same for both circuits. In the whole series of articulation tests about 270 lists of 50 syllables each were called over the circuits, and about 60,000 syllables were recorded.

"Noise" Comparisons. Since the adoption of a frequency-weighting curve by the sub-committee, some tests have been made to compare the relative noise-producing powers of equal single-frequency currents in the telephone receiver with their relative interfering effects as determined by the methods just described.

In brief, these tests comprised measurements of the "noise" caused by the different single-frequency currents in a telephone receiver using the apparatus ordinarily employed by the telephone companies for measuring the magnitude of the noise on circuits subject to induction. In measuring the noise on a given circuit the observer listens with the receiver connected alternately to the noisy circuit and to a source of standard noise and adjusts the amount of the standard noise until in his opinion the noise from the actual circuit and from the standard would produce equal interference with a conversation if carried on over the circuit. By this method much is left to the judgment of the observer and the results obtained by any one observation can be only approximate. For convenience in this series of tests the method was slightly modified in that the setting of the noise standard shunt was fixed and the observer allowed to vary the magnitude of the single-frequency current until he judged the two of equal interfering effect. Nine observers were used, each making the comparison for

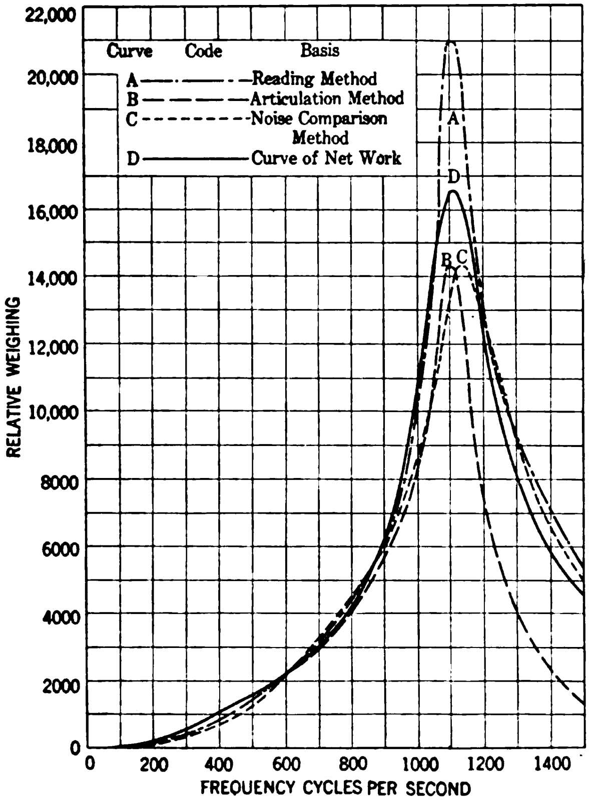

FIG. 5—COMPARISON OF FREQUENCY WEIGHTING CURVES

three different values of noise and for single-frequency currents of 180, 300, 500, 800, 950, 1100, 1300 and 1500 cycles per second. The results are shown by curve C of Fig. 4.

Comparison of Results. The different methods above described afford relative measures of the effects of different frequencies. In plotting the results thus obtained to a common scale, as shown by Fig. 4, the reduction factors were chosen so as to make the different curves coincide as nearly as practicable through the range of frequencies below 800 cycles. The results obtained in the several tests are in surprisingly good agreement.

To facilitate a comparison of all these results with the frequency-weighting curve given by the network, which was chosen with curves A and B as a basis, the ordinates of all the curves of Fig. 4 multiplied by a factor proportional to the frequency are used as the ordinates of the corresponding curves of Fig. 5, together with the frequency-weighting curve adopted.

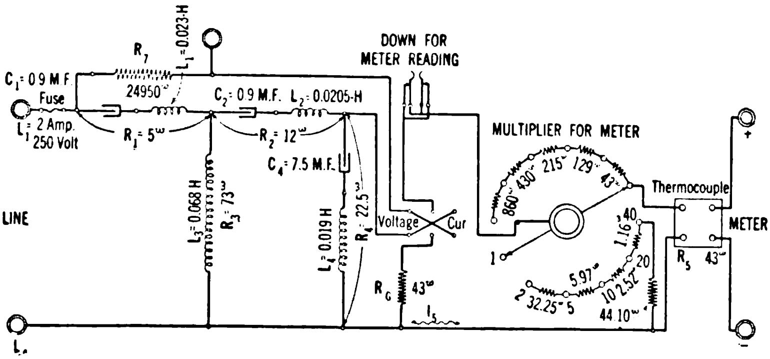

FIG. 6—APPARATUS FOR MEASUREMENT OF TELEPHONE INTERFERENCE FACTOR-DIAGRAM OF CONNECTIONS

APPENDIX B

SPECIFICATIONS OF APPARATUS FOR MEASURING TELEPHONE INTERFERENCE FACTOR

These specifications describe in greater detail the electrical requirements for the network designed to measure the telephone-interference factor which is described in Rule 408 and illustrated in Fig. 2. In addition to the electrical requirements of the essential parts of the network, certain auxiliaries are also described which have been found to be very useful. The network including auxiliaries consists of the following parts: three condensers, four inductance coils, two resistances, one multiplier composed of a six-position dial switch and ten resistances, one vacuum thermocouple, one double-pole double throw switch, one voltmeter contact key and one fuse. These parts are connected electrically as shown in the wiring diagram of Fig. 6.

In a series of fine print notes are given data regarding a network which has been constructed and which satisfactorily meets all of the requirements specified. This network has been designed to give the most satisfactory results at 110 volts as most of the measurements will be made on the low-voltage side of the potential transformers. It may be used however for any voltage not exceeding 700.

Condensers. C_1 should be a mica type condenser having a capacitance of 0.9 microfarad, which should be correct to within 0.5 per cent at 900 cycles. At this frequency the deviation of its phase-angle from 90 degrees should not exceed two minutes. The condenser should be rigidly mounted so that its constants will not change, and should be dipped in some suitable moisture-proof compound. The voltage rating of this condenser should equal that of the maximum voltage with which the network is to be used and should include a reasonable factor of safety.

> This condenser consists of alternate sheets of tin-foil and mica securely fastened between brass mounting plates. It is rated to withstand 1000 volts direct. Its outside dimensions are 3¼ by 3⅝ by 3⅞ in. Its capacitance measures 0.901 microfarads at 900 cycles, and its effective resistance 0.09 ohms corresponding to a phase angle deviation of 1.7 minutes.

C_2 is a mica type condenser having the same requirements as C_1 except that the voltage rating need not exceed 500.

> This condenser is constructed similarly to C_1. It is rated to withstand 500 volts direct. Its outside dimensions are 1⅛ by 3⅝ by 3⅞ in. Its capacitance measures 0.898 microfarads at 900 cycles and its effective resistance 0.09 ohms corresponding to a phase angle deviation of 1.7 minutes.

C_4 may be a paper type condenser having a capacity of 7.5 microfarads, and should be correct to within 0.5 per cent at 900 cycles and at a temperature of 25 deg. cent. The deviation of its phase angle from 90 degrees should not exceed 30 minutes at 900 cycles. The condenser should be suitably mounted in a container which will protect it from mechanical injury and which should be sealed with a suitable moisture-proof compound.

This condenser is made up of selected standard rolled paper units of nominal 2 microfarads and 0.5 microfarads sizes. Each unit is mounted in standard sheet metal containers of the following over-all dimensions: 2 microfarads: 1 25/32 by 1 21/32 by 5 in.

0.5 microfarad: 1¾ by 1 7/32 by 4⅞ in. and sealed with suitable moisture proof compound. The total capacitance measures 7.49 microfarads at 900 cycles and the effective resistance 0.12 ohms at 900 cycles and a temperature of 25 deg. cent. This effective resistance corresponds to a phase angle deviation of 18 minutes.

Inductance Coils. All of the four inductance coils should have non-metallic cores. It is quite desirable that one at least should be of the toroidal type, preferably L_3. In specifying the resistance of the coils allowance is made for the effective resistance of the associated condensers.

L_1 should have an inductance of 0.023 henry which should be correct to within 0.5 per cent at 1100 cycles, and an effective resistance of 4.9±0.1 ohms at 1100 cycles. If this coil is constructed of stranded wire it may be adjusted at 900 cycles.

This coil as constructed is of the solenoid type wound with approximately 550 turns of single silk-covered stranded conductor, composed of 25 strands of No. 32 B. & S. gage black enameled copper wire, and has the following approximate dimensions:

Inside diameter	2 7/12	in.
Outside "	5	in.
Winding length	1 ½	in.

The measured value of the inductance is 0.0230 henry and the effective resistance 4.9 ohms at 900 cycles.

L_2 should have an inductance of 0.0205 henry which should be correct to within 0.5 per cent and an effective resistance of 11.9±0.2 ohms at 900 cycles.

This coil as constructed is of the solenoid type wound with approximately 700 turns of No. 24 B. & S. gage double cotton-covered copper wire and has the following approximate dimensions:

Inside diameter	1 7/16	in.
Outside "	3	in.
Winding length	1	in.

The measured value of the inductance is 0.0204 henry and the effective resistance 11.8 ohms at 900 cycles.

L_3 should have an inductance of 0.068 henry which should be correct to within 0.5 per cent and an effective resistance of 73.0±0.5 ohms at 900 cycles.

This coil as constructed is of the toroidal type. It is wound with approximately 4400 turns of No. 27 B. & S. gage double cotton-covered copper wire on a core of rectangular cross-section, having external and internal diameters of 2¾ in. and 1¾ in. respectively and a height of 1 in. The over-all dimensions of the coil are approximately as follows:

Outside diameter	3 5/16 in.
Axial height	1 11/16 in.

The measured value of the inductance is 0.0680 henry and the effective resistance 73.5 ohms at 900 cycles.

L_4 should have an inductance of 0.019 henry which should be correct to within 0.5 per cent and an effective resistance of 22.0±0.5 ohms at 900 cycles.

This coil as constructed is of the solenoid type wound with approximately 700 turns of No. 27 B. & S. gage double cotton-covered copper wire and has the following approximate dimensions.

Inside diameter	1 7/16 in.
Outside "	3 in.
Winding length	1 in.

The measured value of the inductance is 0.0190 henry and the effective resistance 21.9 ohms at 900 cycles.

Resistances. R_6 is provided so that for either position of the double-pole double-throw switch, the impedance of all branches of the network will remain the same. It should be non-inductively wound and have a resistance of 43 ohms which should be correct to within 0.5 ohm. It should have a continuous current carrying capacity of 0.1 ampere.

R_7 is provided as a multiplier for measuring the terminal voltage. It should have a d-c. resistance of 24,950 ohms which should be correct to within 0.5 per cent. Its inductance should not exceed 0.5 henry at 60 cycles. The unit should be designed to withstand the maximum voltage with which the network is to be used, and to dissipate 20 watts intermittently.

This resistance as constructed consists of approximately 2360 feet of No. 37 B. & S. gage double silk covered manganium wire wound in two sections on a wooden spool. The over-all dimensions of the completed coil are as follows:

Outside diameter	1½ in.
Length	4⅛ in.
Winding depth	½ in.

The resistance and inductance of this unit as measured are 24,960 ohms and 0.5 henry respectively.

Multiplier for Meter. This multiplier should consist of suitable shunt and series resistances so arranged that the input resistance will be 43.0±0.2 ohms for all settings and the ratio of its input to output current variable by definite steps so as to give satisfactory meter readings for any current from 0.001 to 0.1 ampere. The actual ratios of input to output currents should not differ by more than 1 per cent from the nominal values marked on the multiplier.

The multiplier as constructed consists of a six-position dial switch, together with 10 non-inductive units having the following resistances; 860, 430, 215, 129, 43, 32.25, 5.97, 2.52, 1.16, and 44.1 ohms. These should be connected as shown in the wiring diagram of Fig. 6.

Meter. The measuring instrument used with this network should consist of a non-inductive meter having a resistance of 43.0±0.2 ohms at all frequencies and all current values. It should measure the effective value of currents having any wave-shape and should, together with the multiplier give satisfactory readings for all currents from 0.001 to 0.1 ampere.

The measuring instrument used consists of a vacuum thermocouple whose heater is composed of material having a very low temperature coefficient, and which has a resistance of 43.0 ohms. The thermocouple is quite substantial in construction and should be able to withstand without a material change in calibration a heater current three times as large as that which gives a full scale deflection on the meter. The meter used with the thermocouple is a d-c. milliammeter having a sensitiveness which will give, with the thermocouple the current range specified.

Switches. The double-pole double-throw switch shown in Fig. 6 should be of such a design that there will be very little possibility of appreciable contact resistance developing as a result of extensive use. The voltmeter contact key should be inserted as shown in Fig. 6. This key will add materially to the protection of the thermocouple in reducing the possibility of overheating due to excessive currents.

Fuse. The fuse should be designed to operate on a voltage equal to the maximum for which the meter is to be used and with a sustained current of not over 2 amperes.

The fuse as used with the instrument has the following rating:

250 volts
2 amperes.

It is of the cartridge type and is mounted inside the box. When the network is used for a voltage higher than that of the

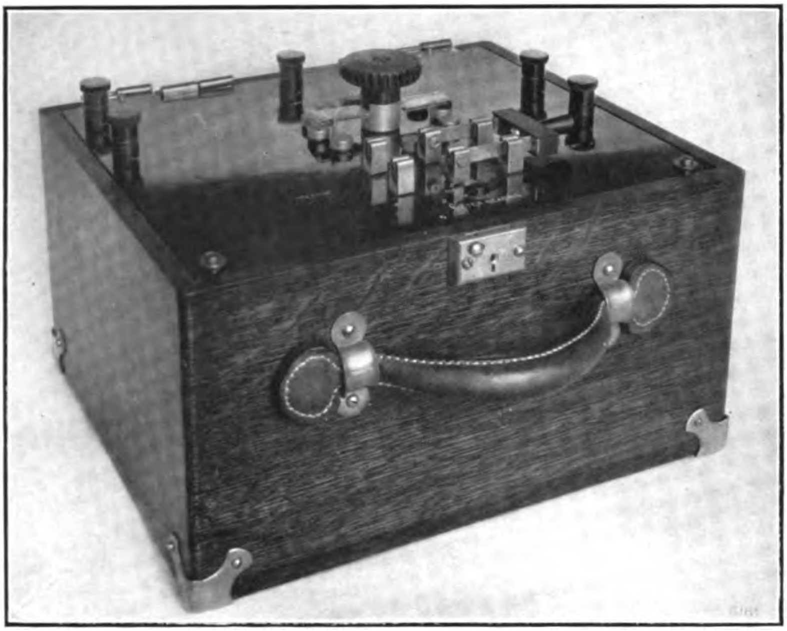

FIG. 8

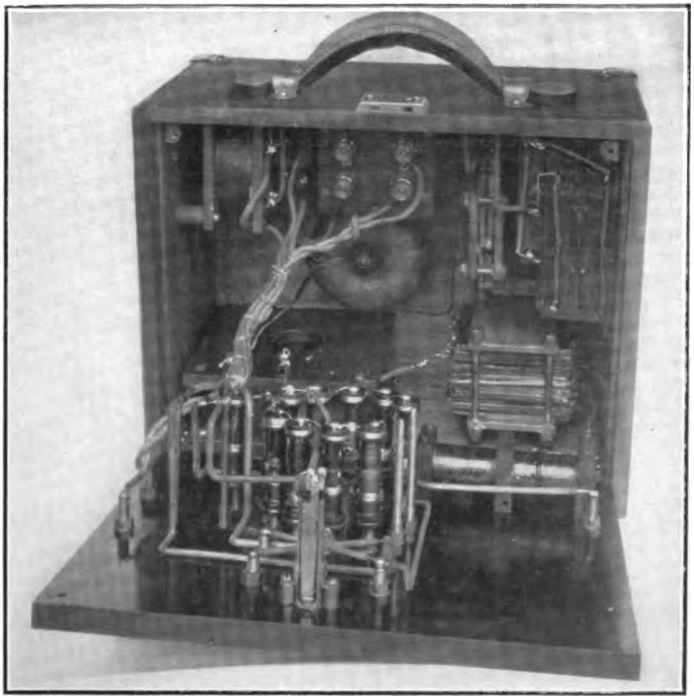

FIG. 9

[OSBORNE]

fuse rating, this fuse should be short-circuited and an external fuse of the proper size used.

Binding Post R. This terminal is provided so that R_7 may be shunted by a resistance connected between R and L_1. This permits the measurement of a lower terminal voltage than would otherwise be possible, which is particularly desirable in calibrating the network. In addition, with the switch in the voltage position, the posts R and L_G provide terminals directly connected to the multiplier. This arrangement is very useful in calibrating the multiplier and the thermocouple.

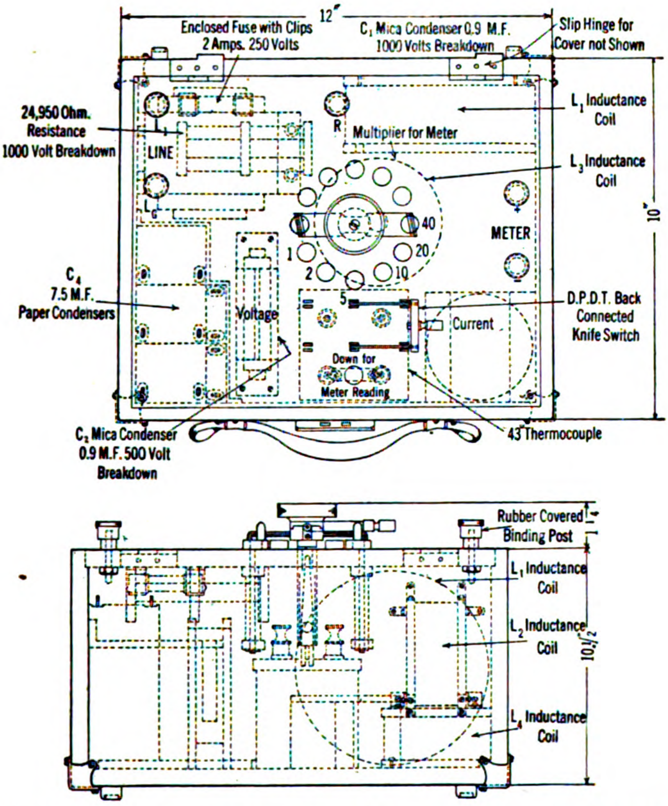
12"
Enclosed Fuse with Clips 2 Amps. 250 Volts
C₁ Mica Condenser 0.9 M.F. 1000 Volts Breakdown
Slip Hinge for Cover not Shown
24,950 Ohm. Resistance 1000 Volt Breakdown
L₁
LINE
L_G
R
Multiplier for Meter
L₁ Inductance Coil
L₃ Inductance Coil
10"
40
20
10
1
2
5
METER
C₄ 7.5 M.F. Paper Condensers
Voltage
Current
D.P.D.T. Back Connected Knife Switch
Down for Meter Reading
C₂ Mica Condenser 0.9 M.F. 500 Volt Breakdown
43 Thermocouple
Rubber Covered Binding Post
1"
L₁ Inductance Coil
L₂ Inductance Coil
L₄ Inductance Coil
10½"

FIG. 7—PORTABLE APPARATUS FOR MEASUREMENT OF TELEPHONE INTERFERENCE FACTOR

Assembly. The parts should be securely mounted in a suitable box which should be as small as possible to make the instrument convenient for field use. All parts should be as accessible as possible. The coils should be arranged so that there is practically no mutual inductance between any two of them and also so that their inductance and effective resistance will not be appreciably increased due to the presence of iron or other metal in their magnetic fields. The wiring should be well insulated and arranged as simply as possible.

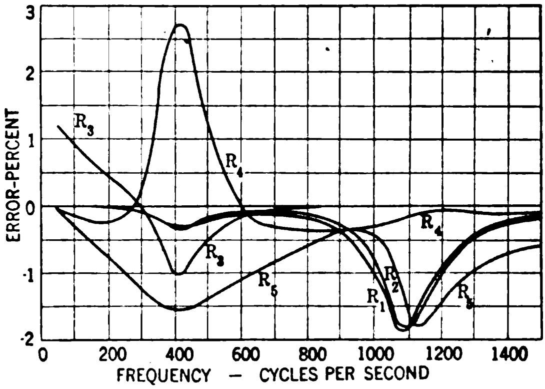

Fig. 10—Effect of a One-ohm Increase in Resistance of Branches of Network

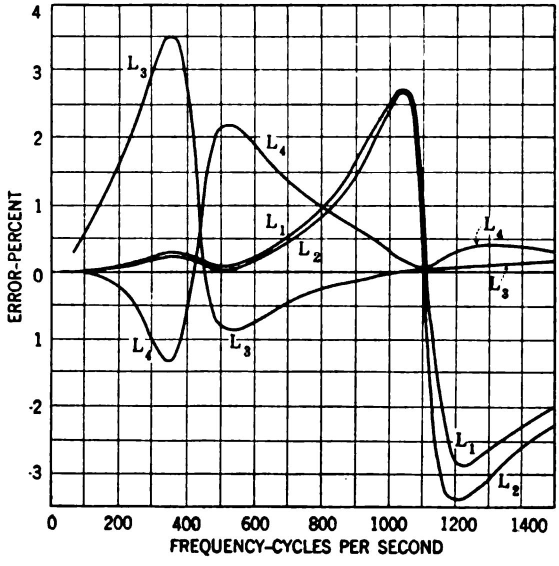

Fig. 11—Effect of a Two-Percent Increase in Inductance of Coils

In Fig. 7 are given working drawings of the apparatus as constructed showing the general arrangement of the parts. All switches are mounted on a hinged top which may be easily lifted to facilitate the inspection of the various parts. The solenoid-type coils are mounted with their axes mutually perpendicular so as to reduce mutual inductance between them. The fourth coil is of the toroidal type which has a negligible stray field. All coils are kept as far as possible from the condensers to reduce any effect which might be produced by their mounting plates or containers. Figs. 8 and 9 are from photographs of the completed apparatus. Its weight is 27 pounds.

Calibration. The network should be calibrated by connecting it to a source of single-frequency alternating current of known and variable frequency. The calibration of the network should include a curve showing the ratio of the current input to the multiplier to the terminal voltage for all frequencies from 0 to 1500 cycles which should agree with the theoretical curve shown in Fig. 1 and described in Section 408 of the Standardization Rules to within 5 per cent at all frequencies. In addition to this frequency-weighting curve the calibration curve of the thermocouple and meter should be given in case the combination is not direct reading. Care should be taken that all higher harmonics are practically eliminated from the testing voltage by the use of filters.

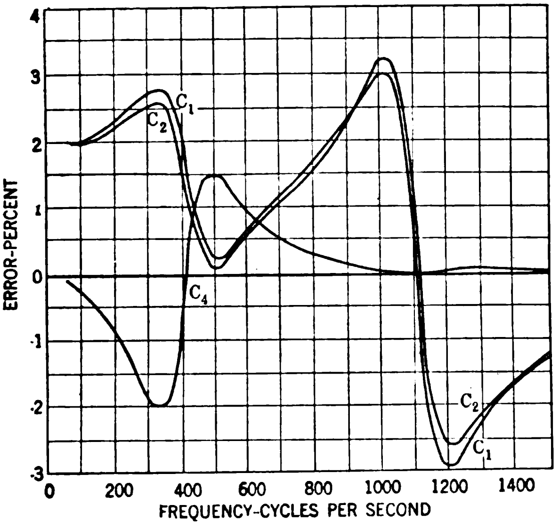

FIG. 12—EFFECT OF A TWO-PER CENT INCREASE IN CAPACITANCE OF CONDENSERS

The following table shows the calibration of the network constructed as described above, together with a comparison with thoretical values.

RATIO OF CURRENT TO TERMINAL VOLTAGE.
MICROAMPERES PER VOLT

Frequency	Theoretical	Actual*	Error per cent.
200	147.8	142.2	3.6
400	998.1	1,010	0.3
600	2,109	2,117	0.4
800	4,143	4,160	0.4
900	6,264	6,340	1.2
1,000	10,530	10,630	0.9
1,100	16,490	16,670	1.1
1,200	12 400	12,350	0.4
1,300	7,983	7,960	0.2
1,500	4,526	4,440	1.8

*At temperature of 21.0 deg. cent.

Effects of Errors in Network Constants. In Fig. 10, 11 and 12 are shown the effects on the measured value of the telephone-interference factor of small changes in the constants of the different elements of the network taken separately. In every case the ordinates represent the percentage increase in the indicated interference factor. In Fig. 10 is shown the effect of an increase of 1 ohm in the resistance of each of the five branches of the network. Fig. 11 shows the effect of a 2 per cent increase in each of the four inductances, and Fig. 12 the effect of a 2 per cent increase in each of the three capacitances. As may be seen from the figures the percentage effect on the interference factor is, in general, less than the percentage error in the element involved.

Presented at the 344th meeting of the American Institute of Electrical Engineers, Toronto, Canada, November 22, 1918.

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ELECTRIC POWER GENERATION IN ONTARIO ON SYSTEMS OF HYDROELECTRIC POWER COMMISSION†

BY ARTHUR H. HULL

THE Province of Ontario is the largest and most populous of the Provinces in the Dominion of Canada, having an area of 407,262 square miles and a population (census 1911) of 2,523,274. Ontario's population is about 35 per cent of the total of Canada's population, and its area is 10.9 per cent of the total area of the Dominion. Ten per cent of its area is water.

Ontario has developed into the greatest manufacturing Province in Canada and as there are no coal deposits in the Province, its abundant water power resources are being more and more utilized to furnish the power required for its varied and increasing industrial development. Other fuels, such as natural gas and petroleum are found in the southern part of the Province, gas along the north shore of Lake Erie and petroleum near Sarnia. The natural gas supply, however, is insufficient for present purposes and the quantity of petroleum produced does not begin to meet the needs of the Province. The demand for electric power has increased during the past ten years to such an extent, that, with the war industries in operation, it became necessary to impose restrictions on private and municipal consumers in order to provide the power required by the war industries. The great saving in coal effected by the use of electric power in Ontario's industries is one of the most important aspects of the electric power situation, and further great savings can be, and will be before long, brought about by the electrification of the steam railroads.

Mr. H. G. Acres* in a monograph on Water-Powers of the Province of Ontario, written in 1915, gives the following summation of water power capable of development, and of water power already developed in the Province.

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*Hydraulic Engineer, Hydroelectric Power Commission.

†The illustrations for this paper have been omitted from these advance copies as they were not supplied in time for publication. They will be shown at the meeting by means of lantern slides.

Division	Potentiality	Developed.
Ottawa River & Tributaries	688,000 h.p.	71,000 h.p.
Great Lakes Tributaries	446,000 "	137,000 "
Hudson Bay Slope	250,000 "	22,000 "
James Bay Slope	1,500,000 "	70,000 "
International Boundary Rivers	2,045,000 "	462,000 "
	4,929,000 h.p.	702,000 h.p.

Of the above total for power developed, about 69,000 horse power is used in pulp and paper manufacture, about 59,000 horse power is used as hydraulic power directly applied, and the balance 574,000 horse power is converted into electric energy for light and power.

This paper will deal only with the generation of electric power by the Hydro Electric Power Commission of Ontario which is now the largest producer and distributer of electric energy in the Province.

The Hydro Electric Power Commission of Ontario, which will be referred to hereafter as the Commission, was formed by the Ontario Government in 1906, and first furnished power over its 110,000-volt lines from Niagara Falls in October 1910, the power being purchased from the Ontario Power Company of Niagara Falls, Ontario. It was not until August 1st, 1917, that the Commission obtained direct control of the generation of power at Niagara Falls, through the Ontario Power Company, but in other parts of the Province, the Commission had started to develop its own power by constructing a hydro-electric plant at Eugenia Falls on the Beaver River near Flesherton, which was put into operation in November 1915, and one at Wasdell's Falls on the Severn River which was started in service in October 1914. In 1914 the Commission acquired by purchase the Simcoe Railway and Power Company, whose generating station at Big Chute on the Severn River had previously supplied power under contract to the Commission's Severn System, supplying the district around the southern part of Georgian Bay. In March 1916 the Government of Ontario purchased the entire holdings of the Electric Power Company which, through subsidiary Companies, was generating power on the South River near Nipissing, on the Otanabee River

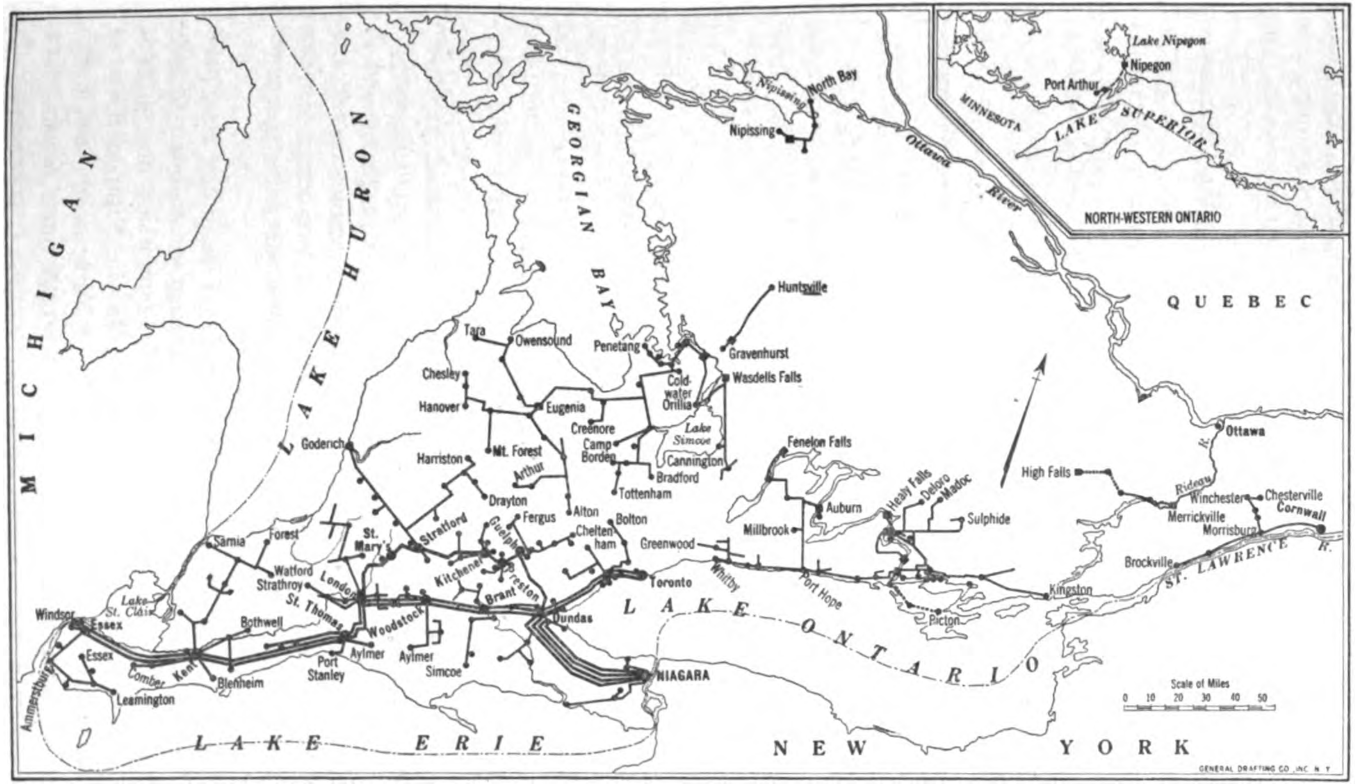

FIG. 1—ELECTRIC GENERATING AND TRANSMISSION SYSTEMS OF THE HYDRO-ELECTRIC POWER COMMISSION OF ONTARIO

at Peterboro, and on Trent River at Healy Falls, Frankford, Campbellford, and Trenton. The operation of the equipments thus acquired was placed in charge of the Commission in June 1916.

The various areas in the Province served by the Commission are designated by Systems as follows

System	Main transmission voltage	Frequency	Phase	Power obtained from
Port Arthur System	22,000	60	3	Kaministiquia Power Company
Nipissing System	22,000	60	3	Commission's Nipissing Station
Muskoka System	22,000	60	3	Comm'n South Falls Station
Wasdell's Falls System	22,000	60	3	Com. Wasdell's Falls Station
Severn System	22,000	60	3	Com. Big Chute Station
Eugenia System	22 000	60	3	Com. Eugenia Station
Central Ontario System	44,000	60	3	Com. Healy Falls Station Com. Auburn Station Com. Campbellford Station Com. Frankford Station Com. Trenton Station
St. Lawrence System	26,400	60	3	M. F. Beach Company
Rideau System	25,700	60	3	Rideau Power Co.
Niagara System	110,000	25	3	Comm's Ontario Power Co's Station Canadian Niagara Co. Electrical Development Co. Queenston Development (future)

PORT ARTHUR SYSTEM

In the Port Arthur System, power is purchased at 22,000 volts, three phase, 60 cycles from the Kaministiquia Power Co., and is delivered to the City of Port Arthur at 22,000 and at 2200 volts, part being transformed in the Commission's Transforming Station in Port Arthur, containing two banks of transformers, each consisting of three 750-kv-a. units connected star-delta with neutral ungrounded.

The first delivery of power was made on December 21st, 1910. The demand has been steadily increasing and in order to take care of the future requirements, the Commission now propose to construct a hydroelectric station on the Nipigon River at Cameron's Pool, about 80 miles from Port Arthur, which will have an ultimate capacity of about 50,000 horse power. The engineering work is now under way for this development. It is proposed to transmit the power at 110,000 volts, three phase, 60 cycles, to Port Arthur. Three other power sites on this same river, when developed, will, together with the Cameron's Pool site, give a total of 150,000 horse power. The needs of the Port Arthur district should, therefore, be amply provided for, but if additional power should be required for this district, another site is capable of development at Silver Falls on the Kaministiquia River about 25 miles from Fort William where with a 350-ft. head a total of 25,000 horse power can be developed. At the present time the electric energy supplied at Port Arthur is used for operation of the street railway, for public and domestic lighting, and for large grain elevators, ship yards, coal docks and miscellaneous industrial purposes.

Nipissing System

The Nipissing System, formerly controlled by the Nipissing Power Company, comprises a generating station on the South River near Nipissing Village, sub-stations in Callander, Powassan and North Bay. The Transmission system comprises 26.5 miles of 22,000-volt, three-phase, circuit on wooden poles. The generating station contains two 450-kw. three-phase 2200-volt 60-cycle 450-rev. per min., horizontal generators with 12.5-kw. 125-volt direct-connected exciters, each unit direct coupled to a water wheel of 925 b.h.p. at 86 ft. head. A 37.5-kw. 125-volt motor-driven exciter is also provided. Three 300-kv-a., 2200/22000-volt single-phase water-cooled transformers connected delta-delta are installed, with one 22,000-volt outgoing feeder.

Water for this plant is taken from the South River through an open canal 900 ft. long, then through a wood stave pipe 6 ft. diameter 2300 ft. long to a differential surge tank 72.5 feet high, close to the power house, a steel penstock connecting thence to the turbines. The storage pond has an area of about 100 acres and the drainage area of the river is about 350 square miles.

Provision was made for extension, and by additional storage works, it is possible to increase the capacity to 2500 horse power.

Muskoka System

The power house on the south branch of the Muskoka River at Muskoka Village was formerly owned by the Municipality of Gravenhurst and was taken over by the Commission in the latter part of 1915, and has been remodelled and enlarged, and now supplies power over a single circuit 22,000-volt, three-phase, 60-cycle line about 26 miles long to Huntsville, and at 6600 volts three phase, 60 cycles, to the Municipality of Gravenhurst over the Municipality's line.

The equipment in this station now comprises one 450-kv-a., three-phase, 6600-volt, 720-rev. per min., 60-cycle generator, direct connected to a 500 b.h.p. turbine; one 750-kv-a. similar 720-rev. per min. generator, direct connected to a 1000 b.h.p. turbine; one bank of three 400-kv-a., 6600/22,000-volt transformers connected delta-delta; double low-tension bus, and single high-tension bus. Four outgoing 6600-volt feeders are provided, two feeding to Gravenhurst and two for future use. One 22,000-volt feeder leaves the station to supply Huntsville. Provision is made in the existing building for a second high-tension feeder.

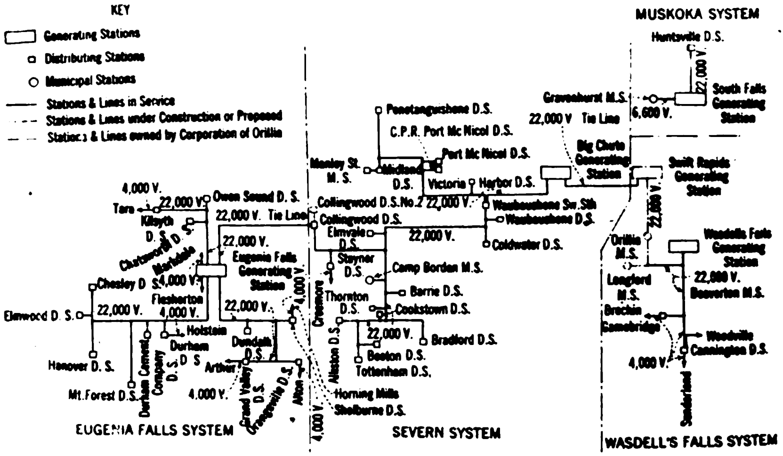

FIG. 2—DIAGRAM OF EUGENIA FALLS, SEVERN, WASDELL'S FALLS, AND MUSKOKA SYSTEMS—60 CYCLES

When this station was taken over by the Commission, only one 450-kv-a. generator was installed. The station was remodelled and enlarged for the larger unit mentioned above, and provision was made for the extension of the building at a future date and for the replacing of existing units so that, when future load conditions require it, there will ultimately be three 1500-kv-a. generators with a turbine capacity of 6000 horse power installed.

The present excitation at this plant is provided by a turbine-driven exciter for the 450-kv-a. unit, a motor-driven exciter for the 750-kv-a. unit, which also has a belted exciter for emergency use, which is so arranged that it may excite either generator.

The hydraulic head at this plant is 102 ft. The water is conducted through one steel and one wood stave pipe, each 946 ft. long to the turbines.

WASDELL'S FALLS SYSTEM

This system comprises a hydraulic generating station on the Severn River at Wasdells' Falls near Severn Bridge, and substations at Beaverton and Cannington. Power is transmitted to Beaverton and Cannington over a single-circuit steel-conductor line at 22,000 volts, three phase 60 cycles, and over a single circuit aluminum tie line at the same voltage to the Commission's Severn System, connecting at Longford with the Town of Orillia 22,000-volt lines from Longford via Orillia to the Big Chute generating station.

The generating station which was constructed by the Commission in 1914 is interesting on account of the low hydraulic head. The normal head is 12 ft., but variations from 9 to 15 ft. occur. The equipment consists of two 400-kv-a., 90-rev. per min., vertical type 60-cycles, three-phase, 2300-volt generators connected through flexible couplings to turbines rated at 600 horse power at 100 per cent gate opening with 12-ft. head. Two exciters, one 20-kw. turbine-driven, and one 30-kw. motor-driven are provided. Two banks of transformers, each consisting of three 2200/22,000-volt 150-kv-a. units connected delta-delta are installed. Two outgoing 22,000-volt lines were provided.

There are in this system, 37 miles of 22,000-volt circuit and 23 miles of 4000-volt circuits from the two sub-stations.

SEVERN SYSTEM

This system comprises a hydraulic generating station on Severn River at Big Chute with substations as shown in the diagram.

The generating station as originally built in 1909 by the Simcoe Railway and Power Company contained three 900-kv-a., three-phase, 2200-volt, 60-cycle, 300-rev. per min., horizontal-shaft generators direct connected to turbines each rated at 1300 horse power under 56-ft. head; two 100-kw. 580-rev. per min., 125-volt exciters direct connected to 200-h.p. turbines; two transformer banks each consisting of three 600-kv-a., 2200/25,000-volt water-cooled transformers connected delta-delta, with two outgoing 25,000-volt lines. An extension to the building has been made by the Commission during the past year, and there is now being installed one 1600-kv-a., three-phase, 60-cycle, 2200-volt 300-rev. per min. horizontal generator direct-connected to a 2300-h. p. turbine. The switching equipment is being rearranged to provide a double high-tension bus for greater flexibility in operation. Space is left for a third bank of transformers, and for two future 22,000-volt line equipments. A double low-tension bus is installed. All power is transmitted at 22,000 volts, three phase, over four lines.

An interesting feature of the transmisssion lines of this system is the long spans across Matchedash Bay at Waubaushene, one being 1135 ft. long and one 858 ft. long. The west shore tower is 175 ft. high, the middle and east shore towers are 88 ft. high. No. 00 B. & S. 19-strand copper conductors are used on these spans.

The water is taken from the river through a canal 500 ft. long to the head works and then through two steel penstocks 170 ft. long to the turbines.

EUGENIA SYSTEM

This system obtains power from a hydraulic generating station constructed by the Commission at Eugenia on the Beaver River which was placed in service in November 1915. Extensions are now almost completed to provide double the output. This development is one of the most interesting in Ontario, and has the distinction of having with one exception, the highest hydraulic head of any plant in Canada, being 552 ft. gross. It is also one of the highest heads in the world using reaction wheels.

The first installation consisted of two 2250-h.p. turbines each direct connected to 1410-kv-a., three-phase, 4000-volt, 60-cycle 900-rev. per min., horizontal-shaft generators having neutral grounded without resistance; one bank of three 900-kv-a., 4000/25,000-volt transformers connected delta-delta, single high-tension and low-tension busses, two outgoing 25,000-volt feeders and two 4000-volt feeders, one each to Markdale and Flesherton. The extensions cover enlargement of the

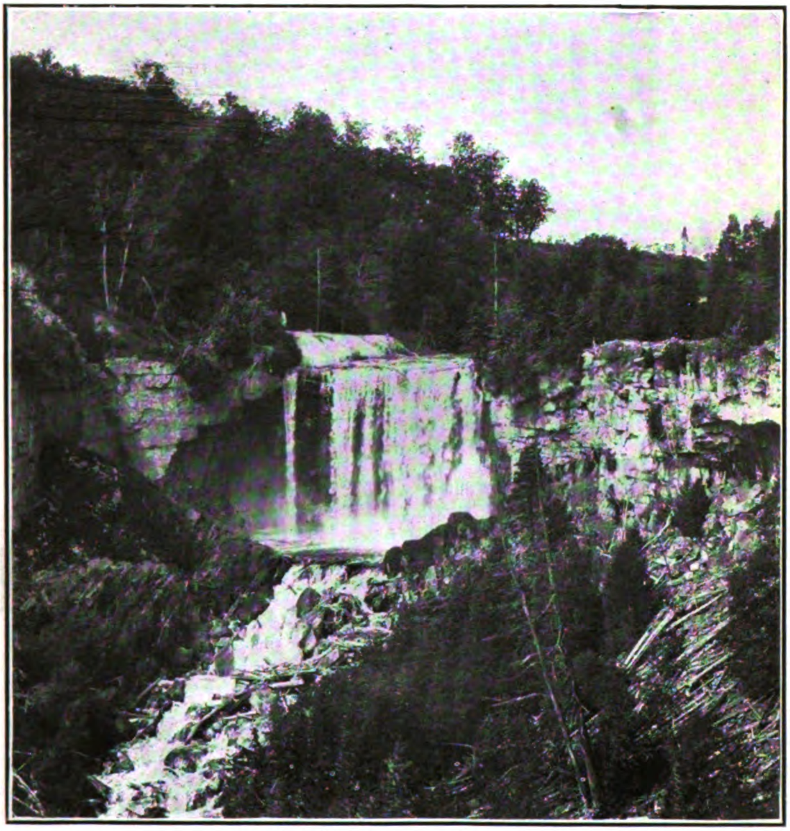

FIG. 3—EUGENIA FALLS [HULL]

building to accommodate two additional generating units, one of which is now being installed, and for double high-tension and low-tension busses, and for six 25,000-volt feeders. The new unit consists of a 2810-kv-a., three-phase, 60-cycle, 720-rev. per min. horizontal maximum-rated generator direct connected to a 4000-h. p. turbine. Each generator has a direct-connected 125-volt exciter of sufficient capacity to excite two generators.

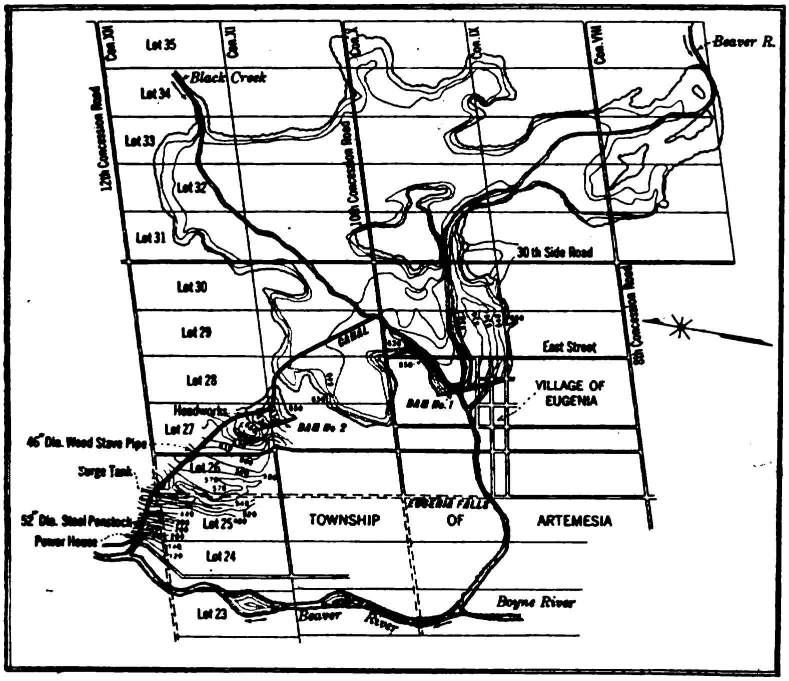

FIG. 4—EUGENIA FALLS—GENERAL PLAN OF POWER DEVELOPMENT ON BEAVER RIVER

The success of the development depended upon the storage of the water of the Beaver River and for this purpose two large storage dams were constructed as shown on accompanying plan. From the head works, a wood stave pipe 46 in. in diameter conducts the water 3400 ft. to the Johnson differential surge tank which is 105 ft. high. From this tank a 52-in. diameter steel pipe is carried 1550 ft. to the power house, which is a brick building 69 ft. wide, 112 ft. long and 34 ft. high above the generator room floor. Actual tests made at this station after the first installation was completed in 1915 gave an overall full load efficiency of 80 per cent which shows how carefully the design was worked out.

Additional power for the Eugenia System will be obtained, when required, by the construction of further water storage systems and of a second pipe line at the Eugenia Falls development and the installation of a fourth unit, also by the construction of a station on the Saugeen River near Lake Huron which operating in parallel with the Eugenia Station will make available a total output for the system of 15,000 h. p.

The Eugenia System comprises 245 miles of 22,000-volt circuit (176 miles of lines) supplying substations at the points shown on accompanying diagram, and 50 miles of 4000-volt circuits. This system is connected to the Severn System by means of a single-circuit three-phase tie line from the Eugenia generating station to Collingwood, a distance of 24 miles.

By means of this tie line and the tie line from Wasdells' Falls to Big Chute mentioned above, the Eugenia, Severn, and Wasdells' systems are paralleled. The generating station of the Town of Orillia on the Severn River at Swift Rapids near Big Chute is also connected into the Severn system.

CENTRAL ONTARIO SYSTEM

Five main generating stations, one on the Otonabee River and four on the Trent River, all operating in parallel, supply this System. These are now fully loaded and plans are being prepared for new stations near Campbellford to provide additional power. The five exciting stations were built by the subsidiary companies of the Electric Power Company. Immediately after the operation of this system was placed under the Commission by the Ontario Government, arrangements were made to install a new unit in the Healy Falls generating station and work on the same is now nearing completion.

The following table gives the data relative to the existing developments, all generators being three-phase, 60 cycles, with 25 per cent overload guarantees:

In addition to the above stations, a 1000-kv-a., three-phase, 60-cycle, 120-rev. per min. horizontal generator owned by the Town of Campbellford in its generating station, a short distance north of the Campbellford station, delivers its output to the 2400-volt bus in this station. Also at Fenelon Falls, a small generating station is operated, containing two 400-kw., 600-volt,

Location	River	Gross head feet	Units				Speed rev. per min.	Type	Generator voltage.
			Number		Rated capacity.				
			Present	Future	Generator kv-a.	Turbine h.p.			
Trenton...........	Trent	20	4	..	937.5	1400	120	Vertical	6600
Frankford.........	Trent	18	4	..	812.5	1200	112.5	Vertical	6600
Campbellford......	Trent	23	5	..	750	1100	150	Vertical	2400
Healy Falls........	Trent	76	3*	1	3750	5600	240	Horizontal	6600
Auburn...........	Otonabee	18	3	1	625	950	150	Horizontal	2-6600 1-2400

*One unit now being installed.

three-phase 60-cycle, 200 rev. per min. generators connected to two 700-h. p. turbines. These feed into the 44,000-volt net work of the Central Ontario system at Lindsay the voltage being stepped up in the generating station through two banks of transformers to 11,000 volts for transmission to Lindsay.

All these stations are on the route of the Trent Valley Canal, the dams having been constructed by the Government of the Dominion of Canada.

The Trenton station, known as Sidney Dam 2 development, being at Dam 2, section 1 of Trent Valley Canal, about one mile north of the Town of Trenton, was placed in operation by the Sidney Electric Power Co. in August 1911. The four generators feed into a single sectionalized bus, and two 6600-volt feeders conduct the current to a transforming station across the road, which station also receives the output of the Frankford generating station at 6600 volts. Two 75-kw. 125-volt exciter units are installed, one being a vertical turbine-driven unit and the other a motor-driven unit. Each of these exciters is capable of exciting all generators at 25 per cent overload with 65 per cent power factor current lagging.

The Frankford station, known as Sidney Dam 5 development, is located at Dam 5 on Section 1 of Trent Canal, about four miles north of Dam 2. This station was constructed by the Sidney Electric Power Company and placed in operation a short time after the Trenton station. It has a single unsectionalized 6600-volt bus and its entire output is fed over two 6600-volt circuits to the transforming station at Dam 2.

The Trenton transforming station contains three 3000-kv-a., 6600/44,000-volt, three-phase, 60-cycle, shell-type transformers connected delta-star with ungrounded neutral, double high-tension and low-tension buses, switching equipment for three 44,000-volt lines and for six 6600-volt lines.

The Campbellford station, known as the Stephen's Dam station, was first placed in operation in 1909 and is near Dam 1, Section 5 of Trent Valley Canal. This station contains four 1125-kv-a., three-phase, core-type, 2400/44,000-volt transformers and two outgoing 44,000-volt line equipments. Excitation for the generators is obtained from two 60-kw. 125-volt exciters, one turbine-driven and one motor-driven, with two 17½-kw. belted exciters for emergency use. The station is situated some distance below the dam, the water being conducted to it through an open head race.

The station at Healy Falls is situated about seven miles above Campbellford. Water is conducted through steel penstocks from the head gates to the turbines. A long tail race excavation through rock was necessary and the enlargement of this tail race, necessitated by the installation of the third generator, is now being completed. This excavation work has been slow and difficult on account of the nature of the rock.

There are three 3750-kv-a., three-phase, shell-type, 6600/44,000-volt transformers installed, with very flexible switching equipment consisting of double 6600-volt buses, two 44,000-volt outgoing lines, a sectionalized 44,000-volt single transfer bus, with a transformer and an outgoing line forming a unit which may be operated independent of the bus. Provision is made for a fourth generator and transformer and for two additional high-tension line equipments. Excitation is provided by two 160-kw. 125-volt exciters, one being turbine-driven and one motor-driven.

The Auburn generating station is located in the north of Peterboro, on the Otonabee River 1200 ft. below the Auburn Dam. Water is taken to the turbines through an open head race 1200 ft. long paralleling the river. This station was built by the Auburn Power Co. and placed in operation in 1912 and no extensions have been made. The turbines are of the four runner type in open wheel pits 40 ft. long, 16 ft. wide and 14 ft. deep. A travelling steel gate 15 ft. 3⅜ in. by 14 ft. 3 in. is provided with motor-driven lowering and hoisting mechanism. The gate is designed to be lowered against the running water in 2½ minutes. Two 90-kw., 125-volt exciters, one being turbine driven and one motor-driven, furnish the excitation of this plant. One generator is wound for 2400 volts and feeds a section of the bus from which 2400-volt feeders may be taken. This section of bus is connected to the 6600-volt section of the bus through a bank of three 200-kv-a., 2400/6600-volt transformers. Feeders at 6600 volts, three-phase, connect this station to the transformer station adjacent which contains two 1875-kv-a., three-phase, core-type 6600/44,000-volt transformers and one outgoing 44,000-volt line connecting into the 44,000-volt net work of the Central Ontario System. Some power is also delivered to Peterboro at 6600 volts from the generating station.

The accompanying map, Fig. 1, and the diagram, Fig. 5, show the location of the generating stations of the Central

Ontario System, and the extent of the transmission net work with substations. Other power sites along the Trent Valley Canal together with those described briefly above will, when developed, provide about 60,000 electrical h. p. with a maximum capacity of 75,000 electrical h.p. The present power output of the system is used for lighting, street railway and manufacturing purposes, a considerable quantity being required at Campbellford for a pulp and paper mill, and near Belleville for cement mills. All transmission lines are constructed on wood poles. The total mileage of 44,000-volt circuits is 372, with 15 miles of 11,000-volt circuit, 16.4 miles of 6600-volt circuits and 52 miles of 4000-volt circuits.

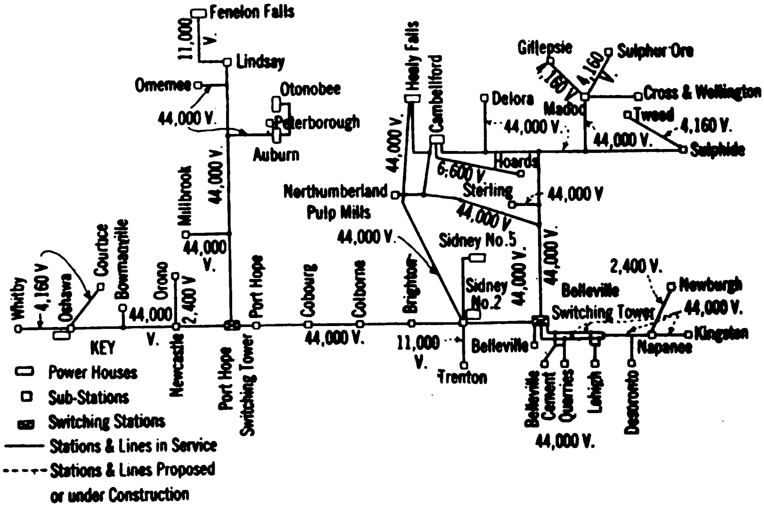

FIG. 5—CENTRAL ONTARIO SYSTEM

ST. LAWRENCE SYSTEM

This system at the present time has no generating station owned by the Commission. Power is secured by contract from the hydraulic station of the M. F. Beach Company at Iroquois, but the amount obtainable proved inadequate and was supplemented by power obtained from the steam generating station of the town of Brockville. As additional power is needed arrangements are now being made to obtain an adequate supply from another source, near Cornwall. To take this power the Commission is now constructing a transforming station near Cornwall which will contain one bank of three 1250-kv-a., single-phase, 63,500/26,400-volt, 60-cycle transformers connected star-delta and switching equipment for two incoming 110,000-volt circuits and for two outgoing 26,400-volt circuits.

This system now supplies power to Brockville, Prescott, Morrisburg, Winchester and Chesterville. Fig. 6 shows this system together with the Rideau system.

RIDEAU SYSTEM

A new net work is being developed called the Rideau system and covering a district in the neighborhood of the Rideau River. Plans are now being prepared for a hydraulic generating station at High Falls on the Mississippi River near Clarendon, a point about 50 miles northerly from Kingston, Ontario. The installation at this point will consist of four 350-kw., 2200-volt, three-phase, 60-cycle, 300-rev. per min. horizontal generators connected to two turbines, one generator being at each end of turbine; and one 875-kv-a. 80 per cent power factor, three-phase, 60-cycle, 2200-volt, 300-rev. per min. generator direct-connected to its turbine with necessary switching and transformer equipment to transmit the full 2100-kw. output, at 26,400 volts to the Rideau system.

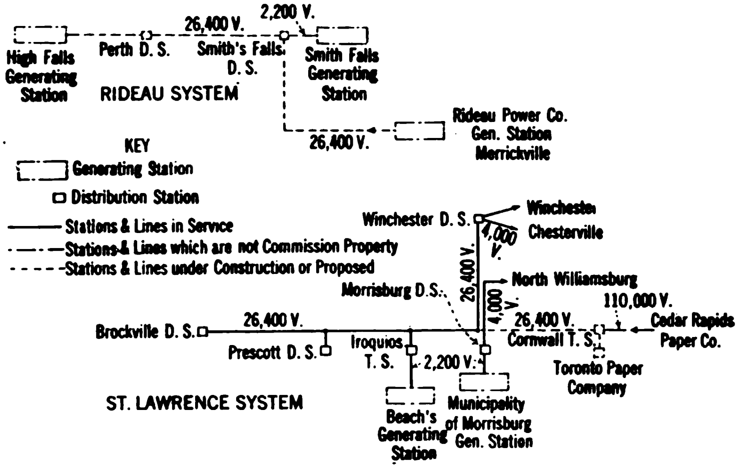

FIG. 6—ST. LAWRENCE AND RIDEAU SYSTEMS—60 CYCLES

A portion of this system is now in operation, power being obtained at 26,400 volts, three-phase, 60-cycles, under contract from the Rideau Power Co. at Merrickville, and transmitted to Smith Falls where at the substation the municipality's own generating stations are paralleled with this system on the low-tension bus.

This system may ultimately be connected with the St. Lawrence System.

NIAGARA SYSTEM

The Niagara System comprises all lines and substations that receive power from Niagara Falls, and covers the entire district from Niagara River to the Detroit River and River St. Clair and north to Goderich and Harriston and east to Toronto. Power is received at a transformer station at Niagara Falls from the Ontario Power Co. (now controlled and operated by the Commission) and fom the Canadian Niagara Power Company, at 12,000 volts, three-phase, 25 cycles and is transformed to 110,000 volts and to 45,700 volts for transmission.

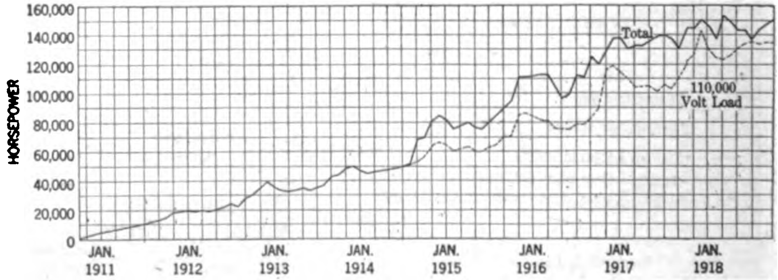

FIG. 9—CURVE SHOWING MONTHLY INCREASE OF POWER LOAD OF MUNICIPALITIES NIAGARA SYSTEM OCTOBER 1910 TO OCTOBER 1918

There is now installed in the Niagara Transformer station 132,000 kv-a. of 110,000-volt transformers in eight banks and 42,000 kv-a. of 45,700-volt transformers in four banks, not including spare units. Four banks of 110,000-volt units are composed of twelve 7500-kv-a., single-phase, shell-type 12,000/63,500-volt transformers, all other transformers being of 3500-kv-a. rating. This station, in point of transformer capacity. is the largest in the world, having a total capacity of 174,000-kv-a, with 7000 kv-a. in spare units additional. Figs. 7 and 8 show two views of this Niagara transformer station.

Four outgoing 110,000-volt circuits feed to Dundas transformer and switching station and from there power is distributed to thirteen 110,000-volt transformer stations. Four 45,700-volt lines feed to Welland to the substations of the Electric Steel & Metals Company, the Union Carbide Co. and

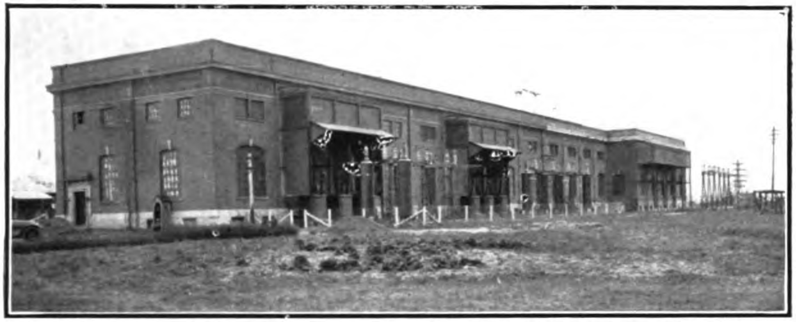

FIG. 7—VIEW OF NIAGARA TRANSFORMER STATION LOOKING SOUTHEAST

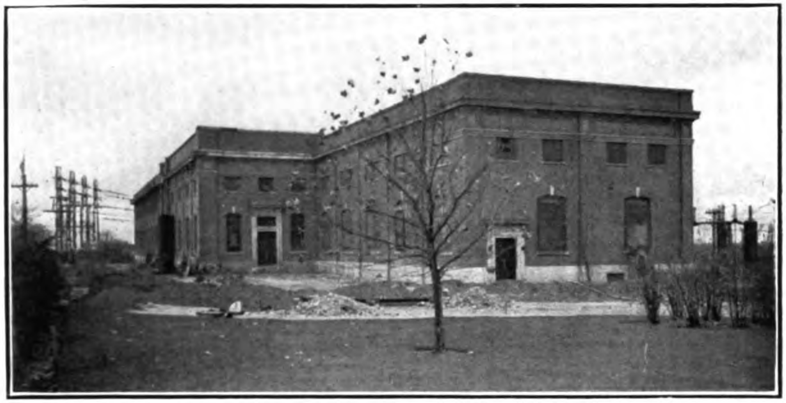

FIG. 8—VIEW OF NIAGARA TRANSFORMER STATION LOOKING SOUTHWEST

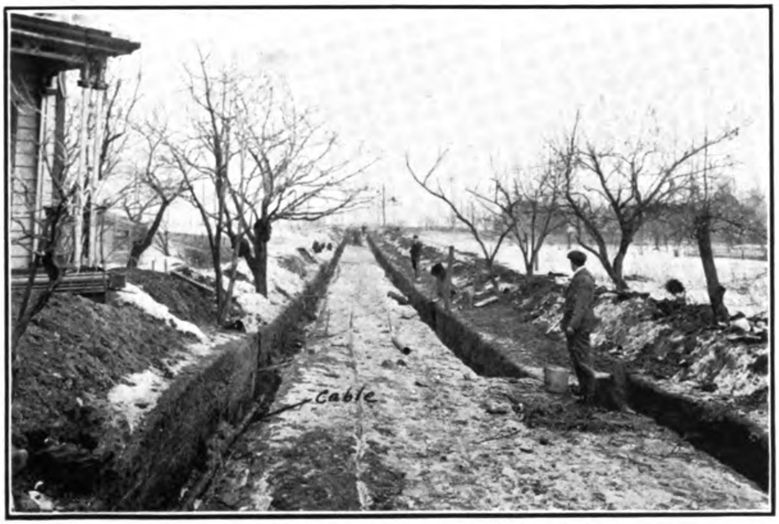

FIG. 11—ARMORED CABLE INSTALLATION [HULL]

the city of Welland. From this latter point a single-circuit, 45,700-volt line runs to Dunnville.

This system was placed in operation in October 1910. The curve in Fig. 9 shows the monthly increase in power load of Municipalities on this System from October 1910 to October 1918. This gives some idea of the growth of the system in this period but the latter portion of the curve cannot be regarded as normal owing to the increase in power required for munitions manufacture and the consequent restrictions on other uses to cut their requirements to a minimum.

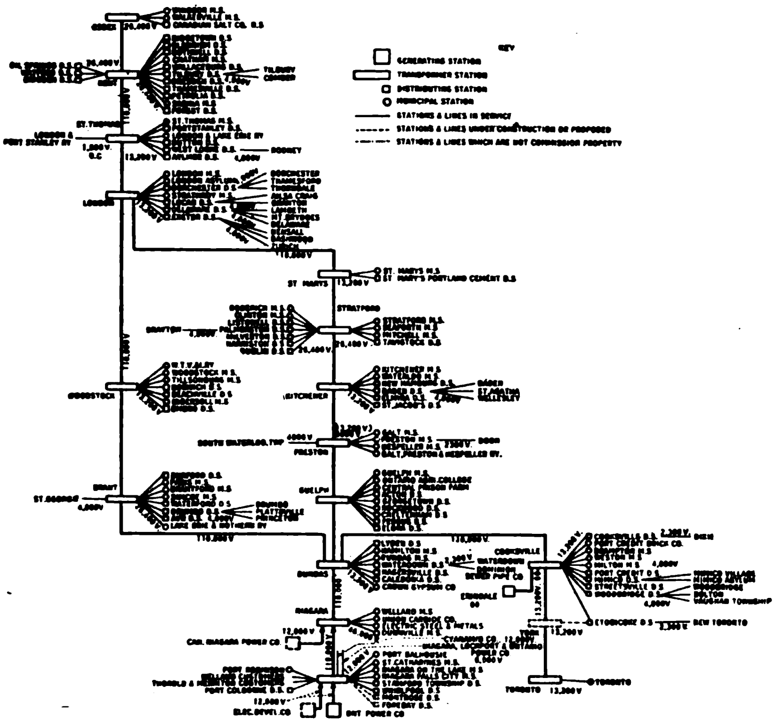

FIG. 10—DIAGRAM OF STATIONS—NIAGARA SYSTEM

The transmission net work, see Fig. 1 and Fig. 10, on this system contains 760 miles of 110,000-volt circuits; 65 miles of 45,700-volt circuits; 529 miles of 26,400-volt circuits; 489 miles of 13,200-volt circuits; 27 miles of 6600-volt circuits; 180 miles of 4000-volt circuits; and 20 miles of 2200-volt circuits. The 110,000-volt and 45,700-volt circuits are carried on steel towers (with exception of one 45,700-volt line from Welland to Dunnville), while the other circuits mentioned above are standard wood pole line construction.

The Commission early in 917 purchased the Erindale Power Company which had a hydraulic generating station on the Credit River at Erindale, 14 miles west of Toronto, containing two 600-kw. three-phase, 60-cycle, 13,200-volt, 200-rev. per min. generators, each direct-connected to a 1000-h. p. turbine designed for a 60-ft. head. The present operating head is about 50 ft. Water is carried from the dam to the power house through a 12 ft. 6 in. diameter tunnel 900 ft. long. Two 60-kw. belted exciters furnish the excitation.

The output of this generating station is now transmitted to the Cooksville transformer station at 13,200 volts, 60 cycles, and is fed into the 13,200-volt, 25-cycle bus in that station through a 1000-kv-a. 60/25-cycle frequency changer set, augmenting the power supply on the Niagara system, and serving also to raise the power factor at the Cooksville station.

It is not the writer's intention to describe the plant of the Ontario Power Co. as descriptions of this plant have appeared in the A. I. E. E. TRANSACTIONS (See Volume XXIV 1905, p. 807). Extensions to the plant have been made since then until, when the operation was taken over by the Commission in 1917, the generating station contained 14 generator units, generating 12,000-volt, three-phase, 25-cycle power with a total rating of 149,012-kv-a. The original excitation scheme had been changed by the Ontario Power Company and a very complete description of this scheme as it now exists may be found in the *Electric Journal* Vol. 1914 p. 612 in article by Mr. J. A. Johnston. The distributing station of the Company contains the 12,000- 30,000- and 60,000-volt buses, the transformer banks and the outgoing line equipments and the control room for the plant. The switching scheme as originally laid out has been considerably re-arranged the buses being sectionalized and connected through reactors, these changes being due to the great amount of power generated and to the large proportion leaving the station at generator voltage.

The Commission, on behalf of the company, is now making extensions to the generating station. The building is being extended north about 90 ft. and a third pipe line of temporary nature consisting of wood stave pipe is being constructed. Two additional generating units are being installed each rated at 15,000 kv-a. maximum rating at 75 per cent power factor.

These new generators are the same speed as the previous units namely 187.5 rev. per min. and the frames are the same size as the 8775-kv-a. units most recently installed. They have however a higher temperature guarantee and are so designed that they may be operated as synchronous condenser at zero power factor if it ever becomes necessary to remove them from this station. These generators were made in Canada, under war conditions, and all parts, except the laminated steel and the insulation, were produced in this country. This speaks well for Canadian industry in these trying times.

Each of these new units is excited by a 125-kw. 250-volt, motor-driven exciter, thus extending the excitation scheme referred to above.

The Ontario Power Company obtain some power from the Electrical Development Company's generating station at Niagara, this being brought into the distributing station on two incoming 12,000-volt feeders. When the present extensions to the distributing station are completed, there will be six main bus sections connected together through reactors. Three of these bus sections will supply the power delivered to the 12,000-volt bus in the Commission's transformer station to which the feeders from the Canadian Niagara Power Company are also connected through a bus reactor. The concentration of generator capacity on this 12,000-volt bus is consequently very great and has necessitated material changes in the switching equipment and bus construction. The studies covering the installation of reactors on this 12,000-volt system have been most interesting. As these studies are still not fully completed, no diagram of the connections for the Ontario Power Company stations and the Commission's Niagara transformer station can be shown at this time. It will be sufficient to state that there is no 12,000-volt bus in the generating station, and that each generator feeds through an automatic oil circuit breaker in the generating station to its individual cables in the cable tunnels up the hill, thence to its group of circuit breakers in the distributing station where switching arrangement are such that each generator and each feeder may be connected to either of two bus sections. In the Commission's Niagara transformer station there is a single sectionalized 12,000-volt transfer bus system so arranged that feeders are connected through an auxiliary bus to the main bus or direct to a transformer bank.

It is of interest to note that the cables for the two new 15,000-

kv-a. generators were purchased after laboratory tests were made on manufacturers' samples to determine the dielectric losses and tendency of compound to flow, and guarantees on dielectric losses were obtained from the contractor.

Another interesting point in connection with the feeders entering the Commission's transformer station is that eight of these are three-conductor, armored cables laid directly in the earth without ducts. These armored cables all have sector-shaped conductors, with 8/32-in. x 8/32-in. paper insulation, a lead sheath and a double steel tape armor with jute bedding and jute covering. They are placed three feet below the surface and two and three feet apart center to center on private right of way. Where these buried cables cross ducts containing other cables, arrangements are provided to moisten the surrounding earth either by sprays above the surface or by porous tile in the ground. Figs. 11 and 12 show views of this armored cable installation, Fig. 10 showing the ventilating pipes at street crossing, the cables being in 6-inch cast iron pipe across the street.

THE QUEENSTON DEVELOPMENT

When the Commission in March 1908 contracted with the Ontario Power Company for 100,000 horse power, it was thought by many that such amount of power would meet the requirement for many years. This supply was however exhausted in 1915 that is, in 5 years from date of first delivery of power, and the additional power secured by arrangements with the Canadian Niagara Power Company has proved insufficient to meet the demands. It became necessary therefore to look to a new development to secure a further supply and the final decision was to proceed with a development called the Queenston Development which is authorized by an Act passed by Ontario Government in April 1917 called The Ontario Niagara Development Act.

Between Lakes Erie and Ontario there is a difference in elevation of 330 feet. The greatest net head now utilized on the Canadian side at Niagara Falls is about 160 ft. Canada is entitled to divert 36,000 cu. ft. per second from the Niagara River, and of this amount, by an Ontario Government Order in Council in 1915, the Commission were allotted 6610 cu. ft. per second. The Ontario Power Company were allotted 11,180 cu. ft. per second, so that, within the control of the Commission, there is now available 17,799 cu. ft. per second.

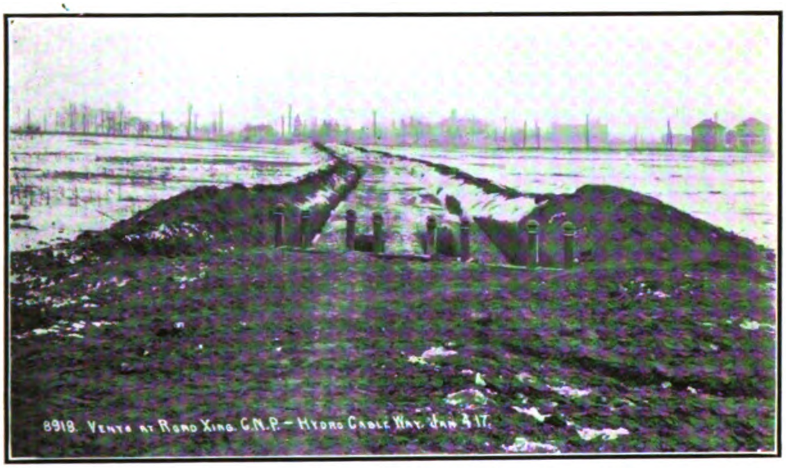
8918. VENTS AT ROAD XING. C.N.P. – HYDRO CABLE WAY. JAN 4 17.

FIG. 12—ARMORED CABLE INSTALLATION

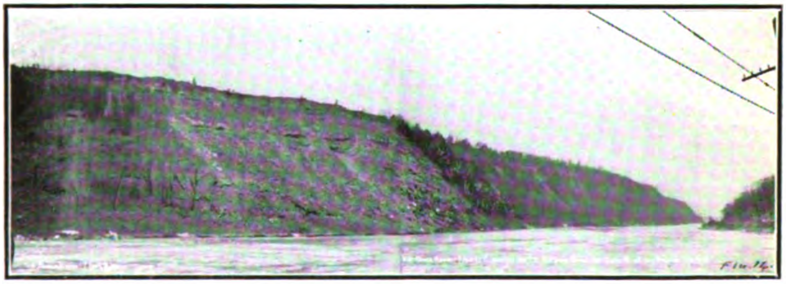

FIG. 14—QUEENSTOWN POWER HOUSE SITE [HULL

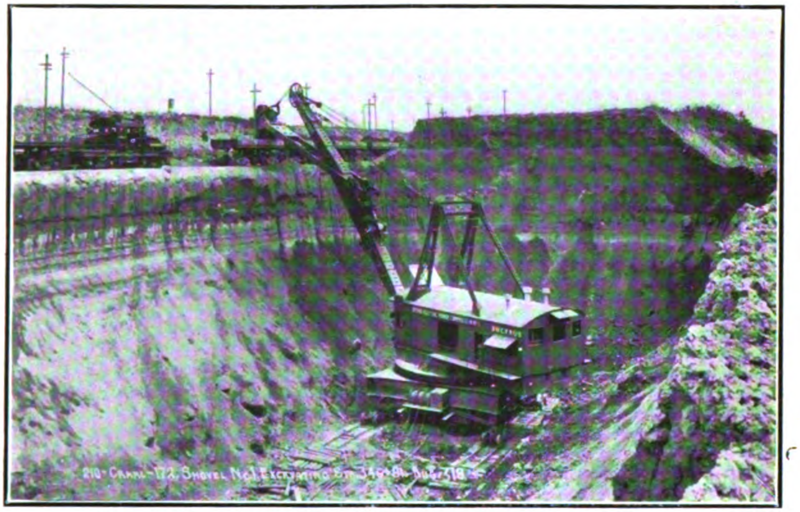

Fig. 15—Large Electric Shovel

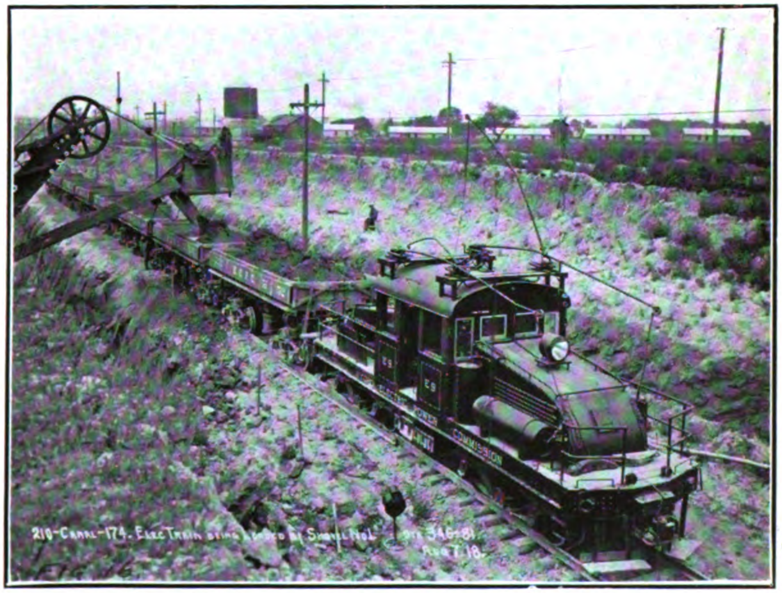
210-Canal-174. Elec Train being loaded by Shovel No1 Sta 346+81 Aug 7. 18.

Fig. 16—Electric Locomotive and Dump Cars [HULL]

To obtain the greatest amount of power from the water available, after careful surveys and studies, it was decided to locate the generating station just above Queenston, and to take water from the Niagara River, through the Welland River (reversing the flow in same) and canals encircling the City of Niagara Falls to Queenston. The first canal is now under construction and the accompanying map of the Niagara District, shows its location. Fig. 13 shows a general plan of this scheme.

The total length of waterway from the Niagara River to the generating station site is about 12½ miles, 4¼ miles of this distance being in the Welland River, and the balance in an excavated canal. The net effective head will be about 305 ft. and the first canal is normally designed for 10,000 cu. ft. per second at minimum low water.

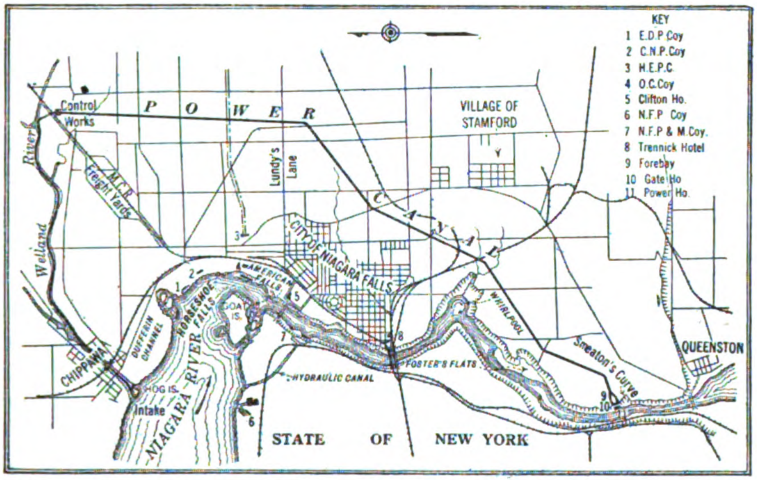

Fig. 13—General Plan of Niagara Power Development—Hydro-Electric Power Commission

The generating station will be located about one mile up stream from Queenston, in the Gorge just at the end of the last rapids in the river. At this point the banks are steep and short penstocks only will be required. Provision is being made for extensions, and right-of-way for two additional canals has been purchased. Fig. 14 shows a view of power house site.

To show the effect of utilizing the greatest possible head of water, it may be pointed out that about 30 h. p. will be developed for each cubic foot per second in this development, whereas about 14 h. p. is all that is obtained in existing plants at Niagara Falls.

The development now under construction is designed as regards canal, forebay, gate house sub-structure and power house substructure, for a capacity of 300,000 h. p. It is proposed to construct the gatehouse and power house superstructure for an initial installation of 200,000 h. p. in four units. The designs are made so that extensions of power house and gate house can be made to almost any extent. Future plans contemplate the use of 100,000-h. p. units.

The turbine speed has been fixed at 187.5 rev. per min. and specification for the generators are now being issued calling for 45,000-kv-a., 85 per cent power factor, 12,000-volt, three-phase, maximum-rated generators of vertical type equipped with thrust bearings to take the weight of the rotating part of the generator plus the downward thrust of the turbines. Direct-connected exciter mounted above the thrust bearings are proposed. The generators will be liberally equipped with embedded temperature detectors so that close and accurate observations may be kept of operating temperatures. The specified maximum temperature of any part of the generator at rated load is 100 deg. cent. with cooling air at 40 deg. cent. The ventilation problem for such units is of great importance, each unit requiring approximately 125,000 cu. ft. of air per minute. Plans for the switching equipment and transforming equipment are now being developed and as they are not in final form, it is not opportune to give any detail description. It is proposed to install double 12,000-volt sectionalized buses, banks of transformers consisting of three 15,000-kv-a., single-phase units, and to lay out the switching equipment so that one generator, one bank of transformers, and one outgoing high-tension line will be a unit. Bus tie reactors will be provided, and the short-circuit current will be limited to a value that can safely be handled on the circuits and circuit breakers.

It is proposed to install two small service generators to supply power required for the station services such as pumping, cranes, lighting, machine shop, ventilating, etc.

To carry on the construction work on this development it was decided to make an extensive use of electric power as possible. Two large electrically operated revolving shovels each fitted with an eight-cu. yd. bucket for earth excavation and of capacity to handle a five-ton bucket in rock were provided. See Fig. 15. The larger of these two shovels has a boom 90 ft. long and a dipper stick 80 ft. long, while the smaller shovel has a boom 80 ft. long and a dipper stick 58 ft. long. Each shovel has motors of a nominal total rating of 715 h. p. on a half hour rating. Three shovels weigh over 300 tons each and have a capacity of 5000 cu. yd. of earth per day. Five other electrically operated shovels are also provided having bucket capacities ranging from 7/8 to 4½ cu. yd.

The railway equipment of the construction work includes 150 dump cars of 20 cu. yd. capacity each, six 40-ton steam locomotives and twelve 50-ton electric locomotives, as shown in Fig. 16.

The electric power required for shovels, trains, air compressors etc., is obtained from the Ontario Power Company's station and is transmitted over two overhead feeders to the Whirlpool Substation located near the Whirlpool. A similar substation will shortly be erected near Montrose on the southerly section of the canal. The Whirlpool substation is of semi-permanent construction and contains switching equipment for the two 12,000-volt incoming lines, and for three 1500-kv-a., 12,000/4000-volt transformers, four 500-kw. 600-volt, d-c. synchronous converters with their 12,000-volt transformers. An adjoining room contains eight air compressors of 1000 cu. ft. per minute capacity each against 125 lb. pressure, belt driven from 550-volt motors, supplied through two banks of 200-kv-a., 2300/550-volt transformers. Air is distributed up and down the canal for a distance of three miles from this substation to operate rock drills, channellers and forges, etc.

Power is distributed up and down the canal by 4000-volt, 25-cycle, three-phase, four-wire, grounded-neutral circuits to which the shovels are connected through flexible armored cable. A double track railway has been built for the full length of the canal with a branch to the main dumping point at St. Davids. These railway lines are electrified, the trolley wires being offset to one side of the track so as not to interfere with the shovels.

The substation at Montrose will be identical with that at Whirlpool and it will similarly serve to supply power for the work on the upper end of the canal.

The extensive use of electric power on the construction of works of the magnitude of this development is working out well and is resulting in a great saving of coal.

The enormous amount of power to be transmitted from this Queenston development involves much engineering study to work out a solution particularly when it is borne in mind that a large amount of capital is invested in existing stations and lines operating at 110,000 volts. These studies are now under way and it is to be hoped that at some later date, there will be placed before the Institute a more complete description of this Queenston Development and its transmission lines connecting in to the Commission's Niagara System.

For those who wish further information on the subject of electric power generation in Ontario, reference may be made to the following:

1. Annual Reports of Hydro Electric Power Commission of Ontario from 1908 to date.
2. The Power Commission Act with Amendments—Ontario Government.
3. Report of Commission of Conservation, Canada, on "Water Powers of Canada" 1911, also 8th Annual Report (1917) of this Commission.
4. Report of Dominion Water Power Branch (Canada) on "Water Powers of Canada."
5. Volumes of "Canadian Engineer" Toronto.
6. Volumes of "Electrical News" Toronto.
7. Transactions of Canadian Society of Civil Engineers, (now the Engineering Institute of Canada.

*Presented at the 345th Meeting of the American Institute of Electrical Engineers, New York,
January* 10, 1919.

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AERONAUTICS IN THE UNITED STATES, 1918

BY GEORGE O. SQUIER

Abstract of Paper

Major General George O. Squier, Chief Signal Officer of the United States Army, reviews in this address the development of Military Aeronautics in the United States up to the date of the armistice, November 11, 1918. The War Department's first heavier-than-air flying machine was produced approximately ten years ago, but for the eight years that followed, the development lagged—in fact less than a million dollars was appropriated for aeronautics in the entire eight years. Then under the pressure of war, the United States by necessity plunged into a gigantic aircraft program—and the accomplishments today are numbered by the score. The Liberty Engine, acknowledged now to be the standard for the world, was produced; an industry new to the United States was developed, and other tremendous strides taken in the science of aerial navigation.

I—Introduction

ALMOST exactly ten years ago (December, 1908) the undersigned had the honor of addressing, from this same platform, the American Society of Mechanical Engineers on the subject of Military Aeronautics, at its annual meeting. The preceding summer months had witnessed the first public flights of the Wright airplane at Fort Myer, Virginia.

The Signal Corps of the United States Army, under date of December 23, 1907, had issued an advertisement and specification for a heavier-than-air flying machine, and the sealed proposals under this specification were opened formally at Washington at twelve o'clock noon on February 1, 1908. The main requirement before acceptance, by the Government, was an endurance test in which the flying machine must remain continuously in the air for one hour without landing.

We all remember the world-wide interest which was aroused by the performance of this new and promising realization of the dream of the ages. During the continuance of the experiments, the eyes of the world were centered upon the little flying field just outside of Washington. The President and Cabinet Ministers were in frequent attendance, and the Congress adjourned from day to day whenever a flight was in prospect.

And then an almost inconceivable thing occurred. The Messrs. Wright having thoroughly demonstrated and fulfilled all of the conditions required by that specification, and the first machine having been duly purchased and paid for, during the eight years following the entire appropriations by this government for military aeronautics amounted to less than a million dollars.

European Powers, however, in their quest for military advantage, quickly interpreted what had happened at Fort Myer, and France, in particular, during these years was responsible for the principal advances in construction and design.

I shall not enter here into the causes, some military, some civil, of this utter unpreparedness, but the outbreak of war found the United States with but a handful of fliers and very few training planes. There was no aviation industry in this country, and the number of professional men trained as aeronautical engineers and designers was so small as to be practically negligible. In this respect the problem of developing the air program was unique. The United States had built ships before, had manufactured clothing, guns, munitions, built cantonments, etc.; and had a splendid body of men trained in these professions and employments, but, outside of a few men there was no one in the United States with experience in the design or building of even training planes.

Once the United States actually had entered the war, the pressure from our Allies and a sudden realization of our real situation in aeronautics led Congress to grant for this purpose, in the Act of May 12, 1917, $10,800,000; the Act of June 15, 1917, $31,846,000, and finally the appropriation of $640,000,000, the largest ever made by Congress for one specific purpose, which was put through the House of Representatives' Military Affairs Committee in two sittings, the House itself in one, the Senate Military Affairs Committee in forty-five minutes; and the Senate itself a week later, becoming a law on July 24, 1917, three months and a half after the outbreak of war.

The task you have given me of presenting within the present hour even an outline of the great undertaking which this nation has accomplished during the last nineteen months in developing the Air Service, is indeed impossible to meet.

I hasten to say at the outset that I can only hope to present to you some of the salient features and accomplishments of this effort. Of the hundreds and thousands of men and women who wrought valiantly and loyally to achieve these results, it will be impossible to mention specific names, or to give anything like just credit or mention to individuals or particular corporations.

Where names are mentioned in connection with certain features of the work, it must not be interpreted that there are not many others who are equally meritorious.

The Honor Roll of this Institute comprises no less than 1,317 men who participated in the Allied forces in the Great War. Of these, 976 were officers, 728 were officers in the American Army, 110 in the Signal Corps, and 52 in the Air Service.

Indeed, it is only in the long reaches of future history that we can form a just estimate of the many lines of endeavor which were set in motion in carrying out this enterprise, and which will, it is hoped, go forward into the future to bear their fruits in times of peace.

II—Statistical Résumé of Aircraft Production and Training

THE work involved in training aviators and obtaining aeronautical equipment in the United States has been of such magnitude as to preclude the possibility of presenting here anything more than a brief résumé of the major accomplishments.

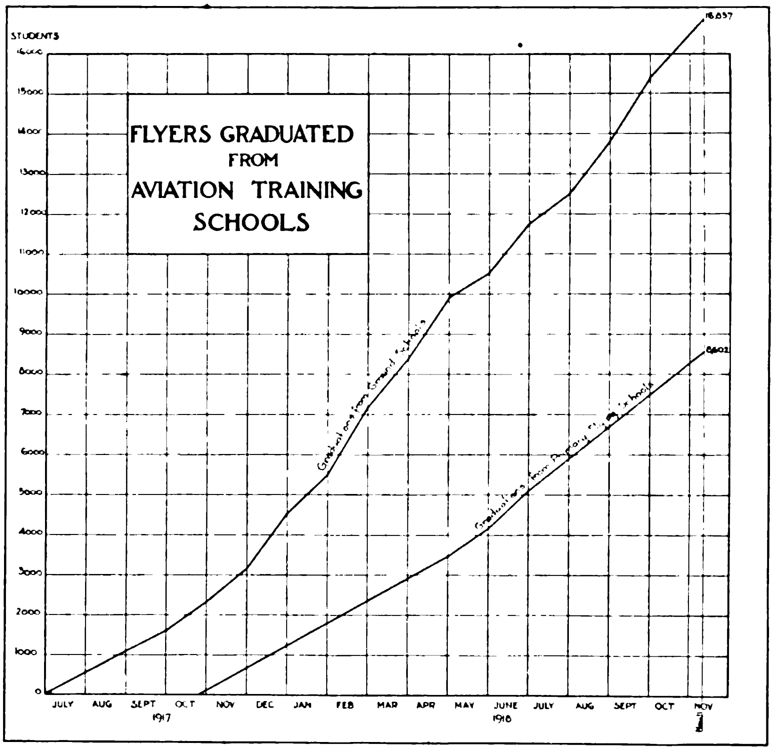


Fig. 1

The data is presented as of six o'clock a. m., November 11, 1918 (the date of the signing of the armistice).

Personnel

More than 8600 fliers have been trained in the United States since its entry into the war. Monthly graduations from ground and flying schools are shown on Fig. 1. The gradually increasing deviation between the two curves on this chart is caused largely by failure of graduates of ground schools to develop into fliers.

There have been training fatalities in the United States, as in all other countries where training has been conducted on a large scale. However, when the fact is realized that our students have flown more than 880,000 hours, which is the equivalent to more than 66,000,000 miles, it will be seen that our training casualties have been astonishingly few. Statistics show that the United States has a lower percentage of fatalities than any other of the allied countries. The monthly average in the United States has been only one fatality for each 3200 hours flown. Training fatalities by months are shown in Fig. 2, and in Fig. 3 are shown the analyzed causes of these fatalities. Two independent investigations made in connection with this paper have developed the fact that more than 90 per cent of training casualties are attributed to the aviator himself. Fig. 4 shows the actual distribution of our fliers overseas.

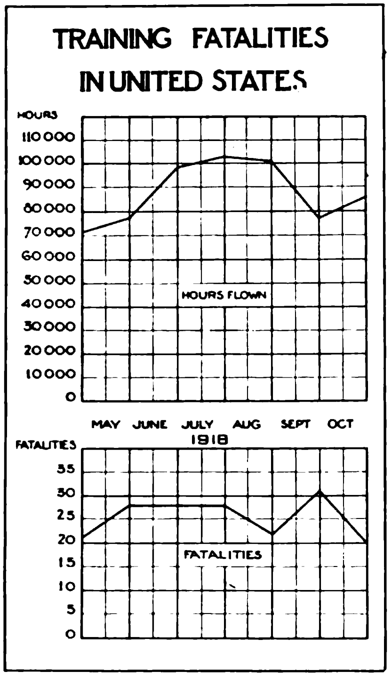


FIG. 2

TRAINING EQUIPMENT

Herewith is presented a tabulation showing the actual production of training material up to November 11, 1918:

Planes		Engines			Propellers
Type Elementary	Number furnished	Name	H.P.	Number furnished	Number furnished
JN-4D	3,762	OX-5		83,18	17,830
SJ-1	1,600	A-7-A		2,250	5,173
Advanced					
JN-4H	929				
JN-6H	803	Hispano	150	3,497	5,295
SE-5	6				
S-4B	100	Gnome	100	278	500
S-4C	384				
E-1	18	La Rhone	80	1,107	358
Total	7,602			15,450	29,156

RAW MATERIALS

Some idea of the quantity of wood necessary for airplane and propeller construction may be obtained from the following table of actual deliveries:

	Spruce Board Feet	Totals
U. S. Army	25,472,000	
U. S. Navy	8,667,000	
England	36,877,000	
France	22,929,000	
Italy	9,147,000	
		103,092,000
	Douglas Fir	
U. S. Army	19,193,000	
U. S. Navy	21,746,000	
England	21,226,000	
France	9,460,000	
		71,625,000
	Port Orford Cedar	
U. S. Army	30,000	
U. S. Navy	1,926,000	
England	2,557,000	
		4,513,000
	Mahogany, Central American	
U. S. Army & Navy	4,524,000	
Allies	4,197,815	
		8,721,815
	Mahogany, African	
U. S. Army & Navy	269,000	
Allies	200,935	
		469,935
	American Black Walnut	
U. S. Army & Navy	2,408,000	
Allies	2,096,876	
		4,504,876
	Quartered White Oak	
U. S. Army & Navy	308,000	308,000
	Cherry	
U. S. Army & Navy	618,000	618,000
	Ash	
U. S. Army & Navy	87,000	
Allies	33,565	
		120,565
	Birch	
U. S. Army & Navy	663,000	663,000

In addition to airplane wood, it was found necessary to maintain strict supervision over the production of airplanes and balloon fabrics. Of this class of material there had been produced to November 11, 1918, 3,187,000 yards of linen; 7,000,000 yards of cotton airplane fabric; 2,647,000 yards of balloon fabric.

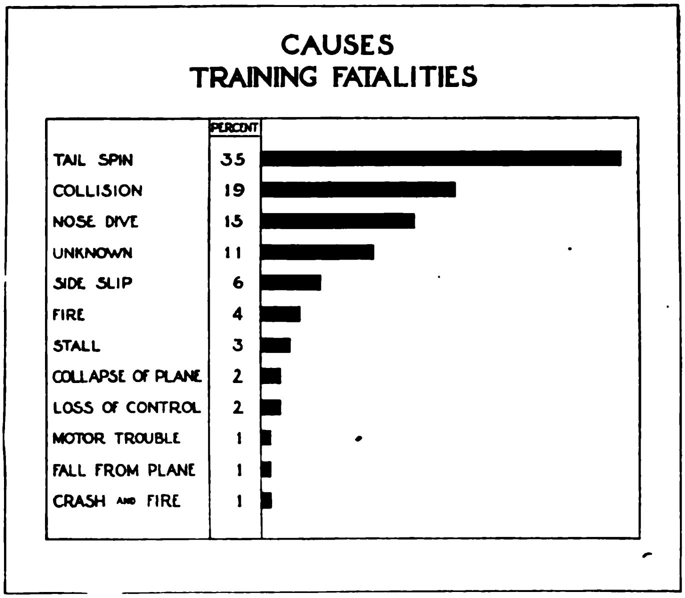


Fig. 3

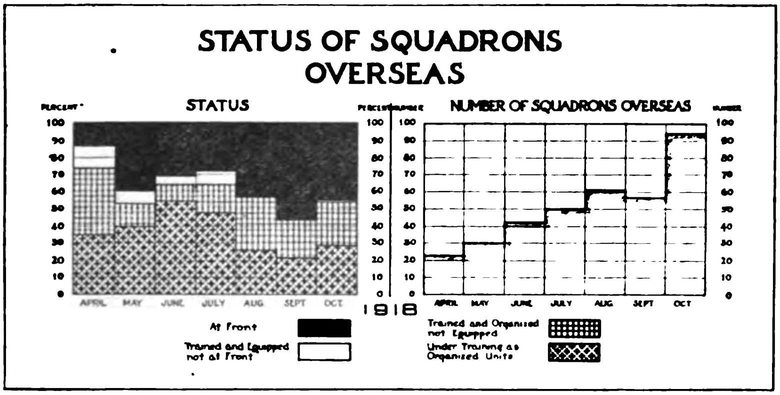


Fig. 4

Accessories

The production of airplane accessories to November 11, 1918 was as follows:

Air Pressure Gages	9,994
Air Speed Indicators	9,051
Altimeters	19,657

Clocks	17,593
Compasses Type "B"	10,179
Fire Extinguishers	12,209
Gasoline Gages	550
Inclinometers	40
Map Cases Rotating	2,417
Oil Pressure Gages	12,187
Oxygen Apparatus	4,318
Oxygen Masks	3,341

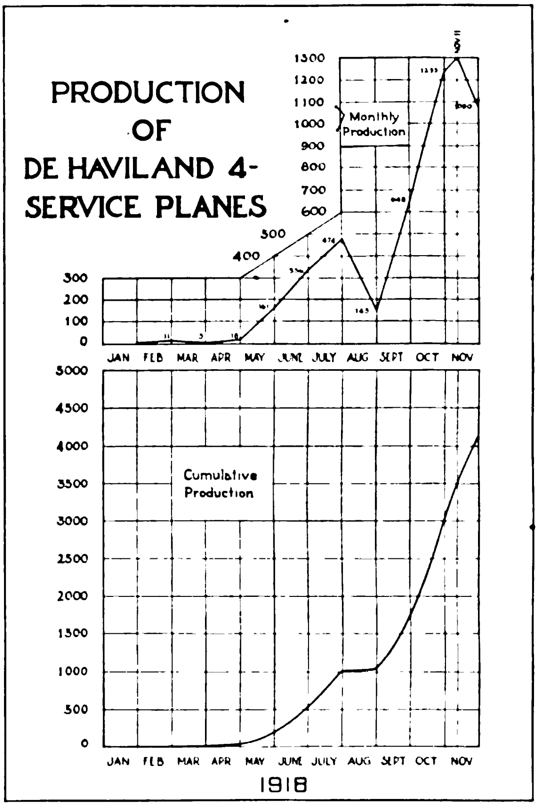


FIG. 5

Oxygen Tanks	12,000
Panels Switch	15,466
Radiator Thermometers	11,984
Tachometers	20,549

Ordnance for use in connection with the air service, such as aircraft machine guns, bombs, etc. were produced under the direction of the Air Service of the Army. Of this type of

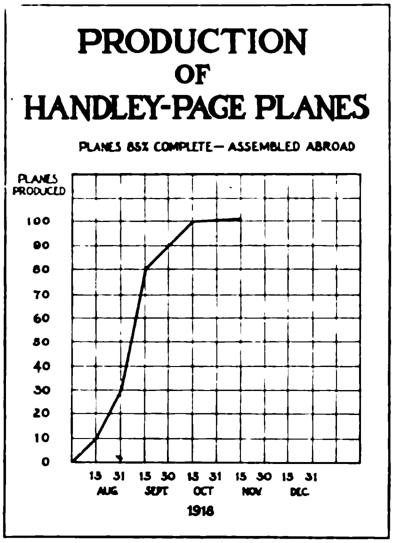
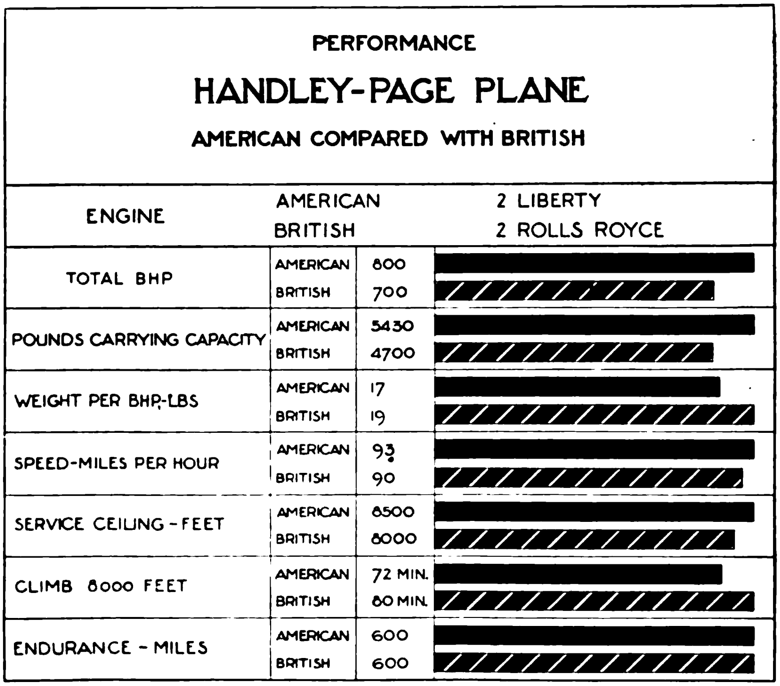


FIG. 6



PERFORMANCE

HANDLEY-PAGE PLANE

AMERICAN COMPARED WITH BRITISH

ENGINE	AMERICAN BRITISH	2 LIBERTY 2 ROLLS ROYCE
TOTAL BHP	AMERICAN	800
	BRITISH	700
POUNDS CARRYING CAPACITY	AMERICAN	5430
	BRITISH	4700
WEIGHT PER BHP.-LBS	AMERICAN	17
	BRITISH	19
SPEED-MILES PER HOUR	AMERICAN	93
	BRITISH	90
SERVICE CEILING - FEET	AMERICAN	8500
	BRITISH	8000
CLIMB 8000 FEET	AMERICAN	72 MIN.
	BRITISH	80 MIN.
ENDURANCE - MILES	AMERICAN	600
	BRITISH	600

FIG. 7

material there were manufactured to November 11, 1918, a total of 81,754 machine guns for aircraft, divided as follows:

31,671	Lewis Guns
11,904	Vickers Ground Guns
411	Vickers Aircraft Guns
37,768	Marlin Guns

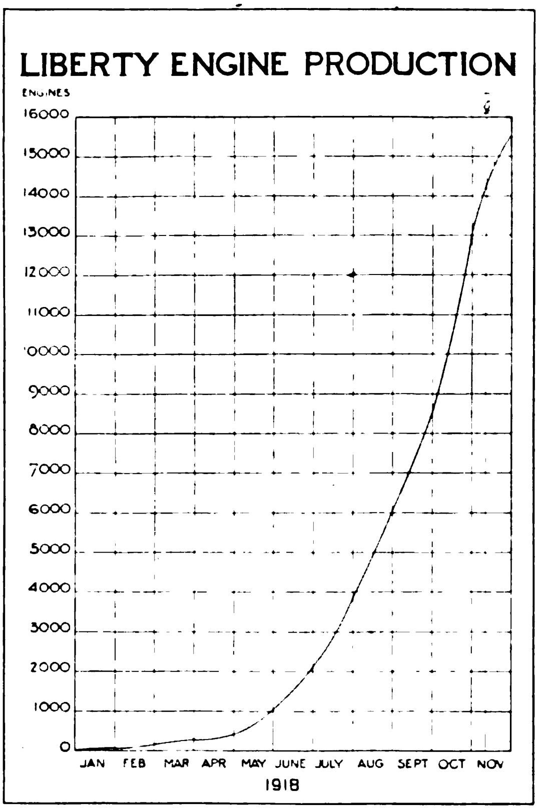


FIG. 8

with the following accessories:

Article	Number Produced
Flexible ring mounts	12,336
Ring sights	13,200
Wing vane sights	12,999
Unit sights	10,104
Auxiliary post and ring	4,585

A total of 510,271 bombs to be launched from air craft was produced to November 11, 1918, of which 114,809 were

LIBERTY ENGINE

COMPARED WITH OTHER AIRPLANE ENGINES

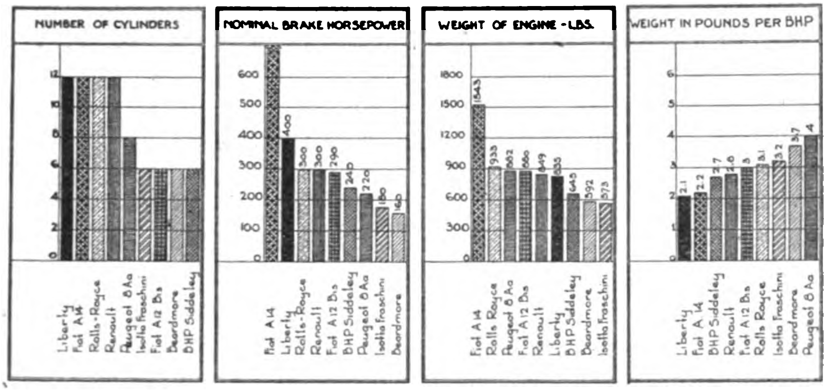


FIG. 9

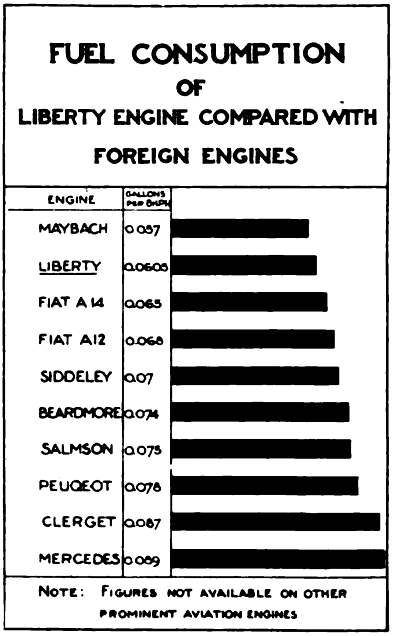


FIG. 10

incendiary bombs; 386,543 were high-capacity demolition bombs, and 8,919 were high-capacity fragmentation bombs.

SERVICE PLANES

DE HAVILAND 4

The production of the De Haviland 4 service plane is shown by months in Fig. 5. It was found necessary to delay production during the month of August 1918 that certain important changes, based on overseas experience with this plane, might be incorporated.

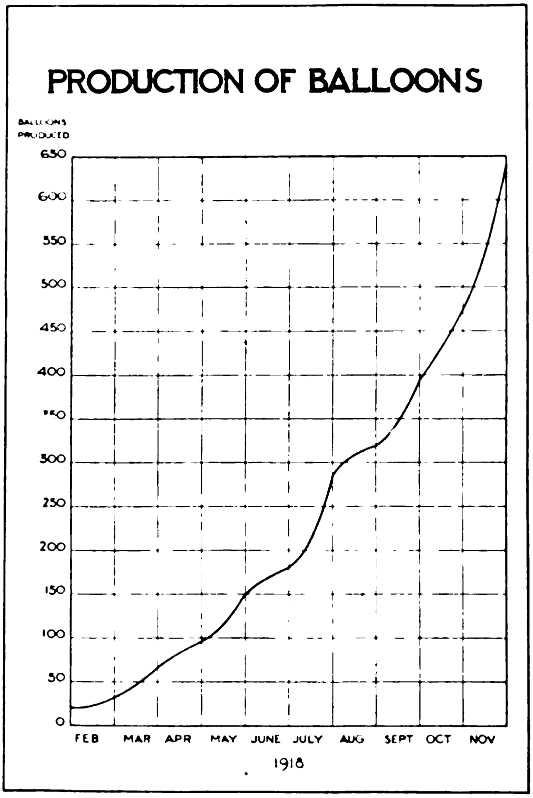


FIG. 11

HANDLEY-PAGE

The production of Handley-Page planes is found in Fig. 6. It should be noted that this production is for planes 85 per cent completed. In other words, planes shipped from this country were not assembled. Fifteen per cent was allowed for assembling abroad. The reason for shipping these planes abroad unassembled is obvious when the size of the assem plane is taken into consideration. An interesting compa of the American Handley-Page plane with its British pr type will be found in Fig. 7.

SERVICE ENGINES

More than 16,000 Liberty engines were produced du the calendar year 1918. To November 11, 1918, more 14,000 Liberty engines were produced, equivalent to 5,700 brake horse-power. Fig. 8 shows the production of Lib engines by months.

A comparison of the weight of the Liberty engine some of the better known foreign airplane engines is show Fig. 9, and fuel consumption in Fig. 10. The basic dat Figs. 9 and 10 came from official communiques from abr In the case of the Liberty engine the results of more than th tests were averaged.

BALLOONS

The production of service balloons met all service req ments. Fig. 11 presents the production of balloons by mor

TYPES OF AMERICAN MACHINES

DEVELOPED, TESTED AND ADOPTED FOR PRODUCTION

On November 11, 1918, there had been developed, te and adopted by the Army four airplanes, on which produc would have started early in the present calendar year. T were the Lepere or L. U. S. A. C.-11 equipped with the Lib engine, the U. S. De Haviland 9-A equipped with the Lib engine, the Martin Bomber equipped with two Liberty eng and the Loening two-seater fighter equipped with the 300- Hispano-Suiza engine. The characteristics of these airplanes are as follows:

Lepere or L. U. S. A. C. 11

Type: Two seater fighter   Engine: One Liberty

Weight empty with water	2468	pounds
Fuel and oil	475.	"
Crew	360	"
Guns, ammunition, etc.	352	"
Gross weight	3655	"
Pounds per b. h. p.	10.15	"
Pounds per square foot	9.33	"
Speed at ground	136	mi. per hr.
Climb to 6500 feet	6	minutes

U. S. De Haviland 9–A

Type: Day bombing and reconnaissance Engine: One Liberty

As a Day Bomber

Weight empty with water	2815	pounds
Fuel and oil	933	"
Crew	360	"
Guns, ammunition, etc.	764	"
Gross weight	4872	"
Pounds per b. h. p.	13.5	"
Pounds per square foot	9.5	"
Speed at ground	121.5	mi. per hr.
Climb to 6500 feet	11	minutes 40 seconds

As Reconnaissance Plane

Weight empty with water	2815	pounds
Fuel and oil	933	"
Crew	360	"
Guns, ammunition, etc.	214	"
Gross weight	4322	"
Pounds per b. h. p.	12	"
Pounds per square foot	8.4	"
Speed at ground	126.2	mi. per hr.
Climb to 6500 feet	7	minutes 30 seconds

Loening

Type: Two seater fighter Engine: One 300 HP Hispano

Weight empty with water	1130	pounds
Fuel and oil	290	"
Crew	360	"
Guns, ammunition, etc.	828	"
Gross weight	2608	"
Pounds per b. h. p.	8.7	pounds
Pounds per square foot	12.1	"
Speed at ground	143.5	mi. per hr.
Climb to 6500 feet	5	minutes 12 seconds

Martin Bomber

Type: Night Bomber Engine: Two Libertys

Weight empty with water	5862	pounds
Fuel and oil	1492	"
Crew	540	"
Guns, ammunition, etc.	1769	"
Gross weight	9663	"
Pounds per b. h. p.	13.4	"
Pounds per square foot	9	"
Speed at ground	113.3	mi. per hr.
Climb to 6500 feet	10	minutes 45 seconds

In order that intelligent comparisons may be made, there are submitted below characteristics of the De Haviland 4 plane:

Engine	One Liberty	
Weight empty with water	2391	pounds
Fuel and oil	457	"
Crew	360	"
Guns, ammunition, etc.	374	"
Gross weight	3582	"
Pounds per b. h. p.	8.95	"
Pounds per square foot	7.12	"
Speed at ground	124.7	mi. per hr.
Climb to 6500 feet	8	minutes

THE NAVAL SEA-PLANE NC-1

One of the most striking accomplishments of the United States in airplane design has been the development by the Navy of the Naval Seaplane or flying boat NC-1. This plane has a central float 46 feet long, a wing span of 126 feet and a total wing area of 2400 square feet. This plane is equipped with three Liberty engines with tractor screws. Fully loaded the plane weighs 22,000 pounds. The weight empty with water is 14,000 pounds.

This plane is the largest seaplane in the world, at the moment, and is an American product throughout. The hull was designed after tank experiments on models. On a recent test this plane made a flight at Rockaway Beach, New York, with fifty-one passengers aboard, getting off in fifty-three seconds. Upon landing it was discovered that the fifty-first passenger was a "stowaway" on board the plane.

III—Remarks on Instruments, Raw Materials and the Training of Personnel

INSTRUMENTS

THE facilities for the manufacture of instruments necessary to give airplanes, pilots and observers their greatest usefulness were extremely limited at the outbreak of the war. The making of these instruments involved practically the formation of an industry new to this country. By June, 1918, twenty types of instruments were in production and being supplied for installation in training, bombing and fighting planes. The list included airspeed indicators, altimeters, compasses, safety belts, oxygen apparatus, radio sets and all other necessary adjuncts for the navigation of the air, and for the safety and comfort of the pilot.

Looking into the future, a reliable and simple "turning indicator" for airplanes is much desired. Furthermore, the development of some form of gyroscopic compass to meet the severe conditions of aircraft service is a problem of great importance. It has been said that the magnetic needle has sense but no power, and the gyroscope has power but no sense.

SPRUCE PRODUCTION

Some idea of the magnitude of the task involved in the procurement of the principal raw material used in the construction of the plane proper, namely spruce, may be obtained from the following figures on production and personnel. On June 30, 1918, the spruce production personnel consisted of 18,305 officers, enlisted men and civilians. Railroads were constructed into the forests of the West Coast and a cut-up plant having a maximum capacity of 9,000,000 board feet of lumber a month was erected at Vancouver Barracks near Portland, Oregon. To November 11, 1918, approximately 174,000,000 board feet of spruce and fir, as shown above, had been shipped of which more than two-thirds went to our Allies.

LINEN, DOPE AND OIL

As it was impossible to produce the millions of yards of linen fabric required for airplane wing and body covering, a suitable cotton substitute was developed and manufactured in this country in quantities sufficient to meet the needs of both

America and the Allies, and at a cost slightly more than half that of the linen fabric formerly used. This accomplishment, theretofore thought impossible, ranks among achievements of the first importance. The dope used on the fabric of airplanes presented many difficulties not only to us but to our Allies. This and other chemicals required soon were being produced in this country in quantities sufficient for their requirements as well as our own.

To meet the extensive demands for a high-grade lubricating oil, castor bean seeds were imported from India and about 108,000 acres planted in this country. Meanwhile, research work with mineral oils was carried on intensively, with the result that lubricant was developed which proved satisfactory in practically every type of airplane engine, except the rotary engine, in which castor oil still is preferred.

TRAINING OF PERSONNEL

The personnel side of the Air Service, including the selection, training, organization, and operation of the flying forces, developed within the fiscal year 1917-18 into an educational system on a scale infinitely larger and more diverse than anyone had anticipated. Teaching men to fly, to send messages by wireless, to operate machine guns in the air, to know artillery fire by its bursts, and to travel hundreds of miles by compass, teaching other men to read the enemy's strategy from aerial photographs, and still others to repair instruments, ignition systems, propellers, airplane wings, and motors, has required a network of flying fields and schools, a large instructional force, and a maze of equipment and curricula.

IV—Some Remarks on the Physical Conception of the Air.

IN a very condensed form I have endeavored to present in the above outline, the salient facts and figures of actual production and deliveries in connection with the air program in the United States up to the moment of signing the armistice. These figures are the cold facts of actual accomplishment of finished product.

I have made no exterpolations to these production curves which would show what flow of Liberty engines and combat planes for instance, we reasonably could expect would result in the succeeding months following the signing of the armistice. I leave this exterpolation to those of you who may be curious.

Behind the production figures of November 11 was mobilized in the United States an industrial army of about 350 firms and corporations employing more than 200,000 men and women. A huge imaginary conduit leading from the factories and assembly shops of America to the fighting front in France was in operation. At any given moment, the number of engines, planes and accessories distributed along the 3000 miles of this imaginary conduit were known accurately and organized in such a way that the flow throughout should be continuous, or that minimum congestion should occur at any point, be it factory door, railway train, embarkation depot, steamship, or debarkation point in Europe.

In order, however, to give an adequate idea of our whole effort, it will be necessary to refer now to certain lines of development, some physical, some chemical and some physiological, which have been set in motion during the progress of this work.

I think we will admit that no world-movement such as we now are witnessing in the development of aerial navigation demands such a close union between science and art. To make a machine to go into the air to transport man is a task set for the hand and brain as never before.

Fifteen years seems a short time when we contemplate what has been accomplished; yet, it was only fifteen years ago, on December 17, 1903, that Wilbur Wright made the first successful flight in a heavier-than-air machine at Kitty Hawk, N. C. To-day Government airplanes have carried the mail between

Washington and New York for seven months, and few of us take the trouble even to watch for these daily flights.

The advent of the first heavier-than-air flying machine begat, as a consequence, a period of intensive interest and study of the physical and dynamical properties of the medium, which are only now in the early beginning, and whose ultimate extensions we can only dimly perceive.

In November, 1916, I had the honor of addressing the National Academy of Sciences at Boston and outlining at that time some outstanding problems for research in connection with aeronautics. Although this was only two years ago, such has been the activity in research in studying air problems that fully two-thirds of the subjects suggested at that time now have been satisfactorily solved and are in actual use in the art.

Technical courses have been established at universities and colleges, and the new profession of Air Engineering is at the moment vying with the older engineering branches.

Everyone knows, of course, that if there were no air there could be no life, but probably very few fully realize its immense importance in almost everything we do. In one condition it is invigorating and gives us a zest for hard work whether mental or physical; in another it leaves us depressed and incapacitated for efficient labor. Numerous manufacturing processes are radically affected by the amount of moisture in the air, and many others by its temperature. Power is transmitted by it; we communicate our thoughts to one another by vibrations of the air; and by its aid we recently have acquired our swiftest mode of travel. Obviously then, a knowledge of the composition, structure, and physical properties of this universal medium is of such vital importance as to justify most painstaking study and research.

In the last few years, for instance, several elements: helium, argon, neon, krypton, xenon, have been found in the atmosphere that previously were unknown and even unsuspected, for they were not required by the Mendeleoff table of the elements as then understood. One of these, argon, amounts to nearly one part in a hundred of the whole atmosphere, and yet through decade after decade of chemical investigations involving countless thousands of air analyses, it, and all its family of gases, remained undiscovered.

Recently, too, means have been found for drawing directly on the atmosphere for an inexhaustible supply of nitrogen compounds used in the production of powerful explosives, fertilizers, and many other things of industrial value.

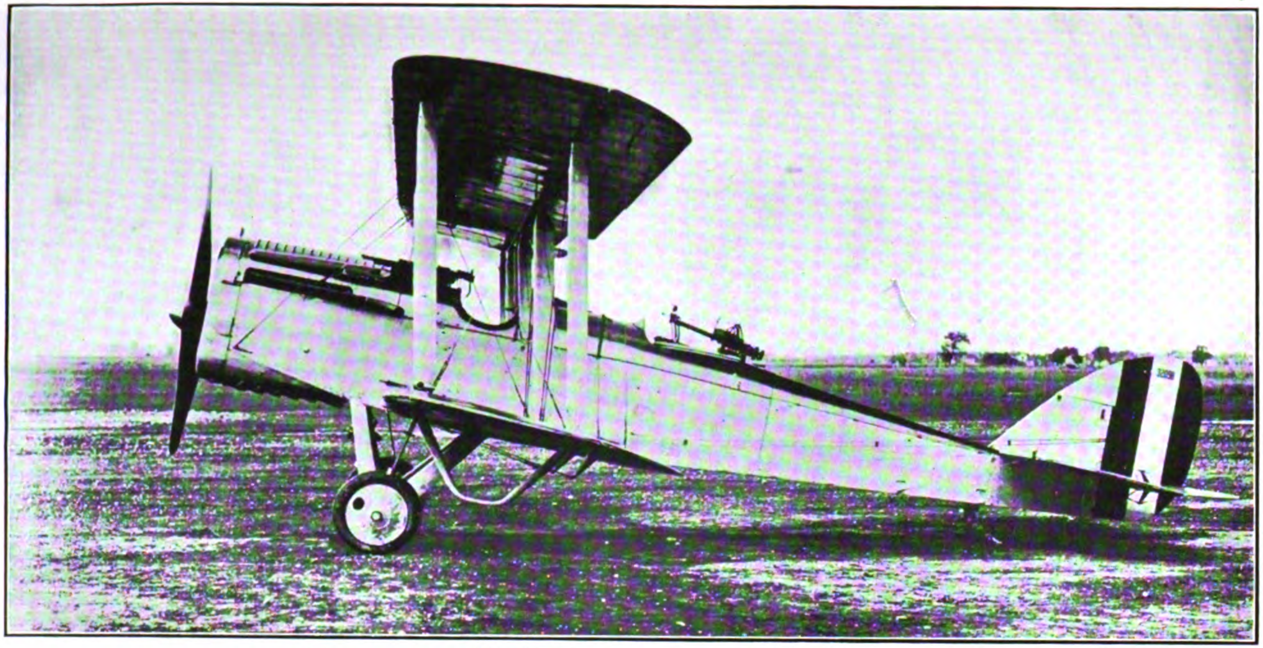
The first eighteen years of the present century have witnessed a wholly new and startling flood of physical knowledge which has resulted in profoundly modifying our conceptions of electricity and matter, as developed in the nineteenth century. These two great subjects have been brought together and now are recognized as one and the same subject.

What we called self-induction now is considered to be only inertia. Mass is supposed to be wholly electrical and a vector instead of a scalor quantity. The most fundamental of all physical constants, the electron, has been isolated and its charge measured. Electricity from whatever source is made up of these electrons and even metallic conduction consists of the actual projection of these granular units along the conductor.

A gas like the air, on the present view, is not a continuous medium, but is composed of many individual structures which preserve their indentity and individuality during the normal life of the gas. These largest units are known as molecules, and they are each moving with considerable velocity on the average, the path of each being for the greater part a straight line until two approach near to each other. The forces that these two exert upon each other reach out into the medium which surround them both, creating a region of intense field at sufficient distance away from each so that their integrity is not disturbed.

When the two molecules approach each other, they are deflected off without collision, preventing a catastrophe much as a comet coming into the solar system is merely deflected by the action of the sun, and does not fall into it unless it makes a direct hit, the chances of which are extremely small. The gas pressure of the air upon the walls of the containing vessel merely is the reaction of these deflected molecules that come into close proximity with the more fixed molecules of the container.

If we consider for a moment a cubic centimeter of air under standard conditions, we know that the number of the largest structures therein, the molecules, is a constant, and is about 2.705×10^{19}. It does not matter what kind of a gas we have, whether hydrogen, oxygen, nitrogen or compounds like methane carbonic acid, etc; the number of molecules remains fixed. In fact, we probably can determine the number of molecules in a



DE HAVILAND 4—LIBERTY ENGINE

[SQUIER]

cubic centimeter of a gas more accurately than we can determine the number of inhabitants in New York City, in spite of the fact that the number is slightly more than twenty-seven billion billion.

By measuring the weight of the cubic centimeter of air and dividing this by the number of molecules contained therein, we obtain the weight of the largest structure composing the air, namely, the molecule. The structure of the molecule, while sufficiently enduring to remain together as a unit in the normal condition of the gas, yet is not strong enough to withstand forces that may be easily brought to bear upon it by chemical means to cause it to separate into still smaller units known as atoms. In the nitrogen and the oxygen of the air there are but two atoms making up each molecule, so that each structure in air can only be divided into two by any means at the disposal of the chemist.

The atoms, however, have been broken up into still smaller units, but it can be done only with great difficulty, comparatively speaking, and until recently, the difficulty was so great that they earned the name atom, signifying that they could not be cut in two. They are far more enduring structures than the molecule.

The only two kinds of things that ever have been obtained thus far by the breaking up of the atoms, of all kinds, are the so-called positive ions and negative electrons, and these remain today as things which never have been broken up into smaller components. Whereas the negative electron has been isolated from gross matter the positive charge never has been dissociated from matter. The present idea of physicists is that we have found an ultimate constituent of all gross matter. The mass of this negative electron has been measured, and the mass of the smallest atom, hydrogen, is 1845 times greater than that of the electron.

We regard the atom as consisting of a positive nucleus about which negative electrons are ceaselessly revolving. The dimensions of the negative and positive constituents of atoms, in comparison with the dimensions of the atoms themselves are like the dimensions of the planets and asteroids in comparison with the size of the solar system. Here then the master physicists with consummate skill have built up for us an alluring conception of miniature solar systems of which all gross matter is composed "A mighty maze! but not without a plan."

In the light of the foregoing conception of a cubic centimeter of air, imagine if you can, what a compilcated thing is the result of an orchestra playing perhaps one hundred instruments and two hundred voices singing in chorus, accompanied by the orchestra. The cubic centimeter of atomic worlds, in this case, becomes subjected from without to a great number of superimposed frequencies representing each and all of the individual instruments, as well as the innumerable harmonics required to indicate the qualities of the human voices; yet our medium is sensitive enough to respond accurately to each and every one of these frequencies simultaneously, and synthetically adds them together and produces a resultant envelope curve of pressure which the marvels of the human ear are able to analyze and interpret into its elements. A medium which has such qualities as to be capable of acting and reacting in this delicate manner, and at the same time when moved bodily with the velocity of a tornado may cut down trees and buildings as if by a giant steel knife, is a medium the possibilities of which for future research we, at present, only dimly perceive.

V—The Production of Helium on a Commercial Scale

ONE of the greatest scientific achievements of the present war from a technical standpoint is the production of helium in balloon quantities. This gas is non-inflammable and has about 92 per cent of the buoyant effect of hydrogen. Its name is due to its having been discovered in the sun's atmosphere through a characteristic line in the solar spectrum, before its presence on the earth, or any of its properties were known. It first was obtained in minute quantities by Ramsay in England some twenty years ago by heating certain radioactive minerals, in which it occurs because it is a disintegration product of radium. Its pre-war scarcity may be appreciated from the fact that, up to two years ago, not more than 100 cubic feet ever had been obtained, and the usual selling price was about $1700 a cubic foot.

Notwithstanding so discouraging an outlook someone in the British Admiralty had imagination enough to propose the large scale separation of helium from certain natural gases in Canada, that contain about one-third of one per cent of it, and experiments were undertaken at the University of Toronto. Soon after the entry of the United States into the war, the Bureau of Mines, learning of the problem from a British confidential memorandum, persuaded the Signal Corps and the Bureau of Steam Engineering of the Navy to approve and finance jointly an experimental program on a large scale. Thanks partly to the unusually rich sources of supply in this country, and partly to the skill of the two commercial companies whose services were enlisted, and to the enthusiasm of the Bureau of Mines Staff and of Mr. Carter, of the Navy, who for a time represented the Army as well in the project, such success was achieved that, at the cessation of hostilities, there was compressed and on the dock ready for floating 147,000 cu. ft. of nearly pure helium, and plants were under construction to give at least 50,000 cu. ft. a day at an estimated cost of not more than ten cents a cubic foot.

The production of a balloon gas that assures safety from fire opens up a new era for the dirigible balloon. In November, 1917, a Zeppelin made the trip from Bulgaria to German East Africa with twenty five tons of medicines and munitions, only to find that the German forces already had been dispersed, and returned safely to its base without landing. With a non-inflammable gas, not only comfortable and expeditious, but also safe transcontinental and transatlantic travel in dirigibles will, it is believed, soon be commonplace.

VI—Meteorological Service of the Army

IN August, 1917, the Chief Signal Officer directed Lieut. Colonel R. A. Millikan to organize an Army Meteorological and Aerological Service, the purpose of which was three-fold:

a. To provide the American Expeditionary Forces with all the meteorological and aerological information needed.

b. To supply the aviation fields, the coast artillery stations, the ordnance proving grounds, and the gas warfare service within the United States with such meteorological and aerological data as might be useful to them.

c. To undertake for the first time in the history of the world the problem of mapping the upper air currents over the United States, the Atlantic, and Western Europe in aid of aviation, and particularly with reference to transatlantic flight.

In carrying out the first of these projects, there were selected approximately 550 men of high qualifications, most of them physicists or engineers who were given a two months' course in meteorological and aerological theory and observations at College Station, Texas. Three hundred and fourteen of these men were sent overseas where they have been operating as an effective and well organized branch of the work of the A. E. F. In addition to furnishing a general weather forecast for the A. E. F., this service has supplied a meteorological unit to each aviation post, each gas service post, each artillery post, and each sound-ranging post of the American Army in France. Under the effective direction of Major W. R. Blair, one of the most experienced aerologists of the United States, commissioned for the service from the Weather Bureau, about twenty upper-air stations were established in France and England and a forecast based on data furnished by these stations made regularly to the A. E. F.

For the accomplishment of the second element of the program, twenty eight stations manned by 150 men, all carefully picked at the start and well trained at College Station, have been established for furnishing local data as to either surface or upper-air conditions, or both, to the flying fields, artillery posts, and proving grounds in this country. The largest of these stations is that at the Aberdeen Proving Ground, which is manned by twenty two men and furnished to the Bureau

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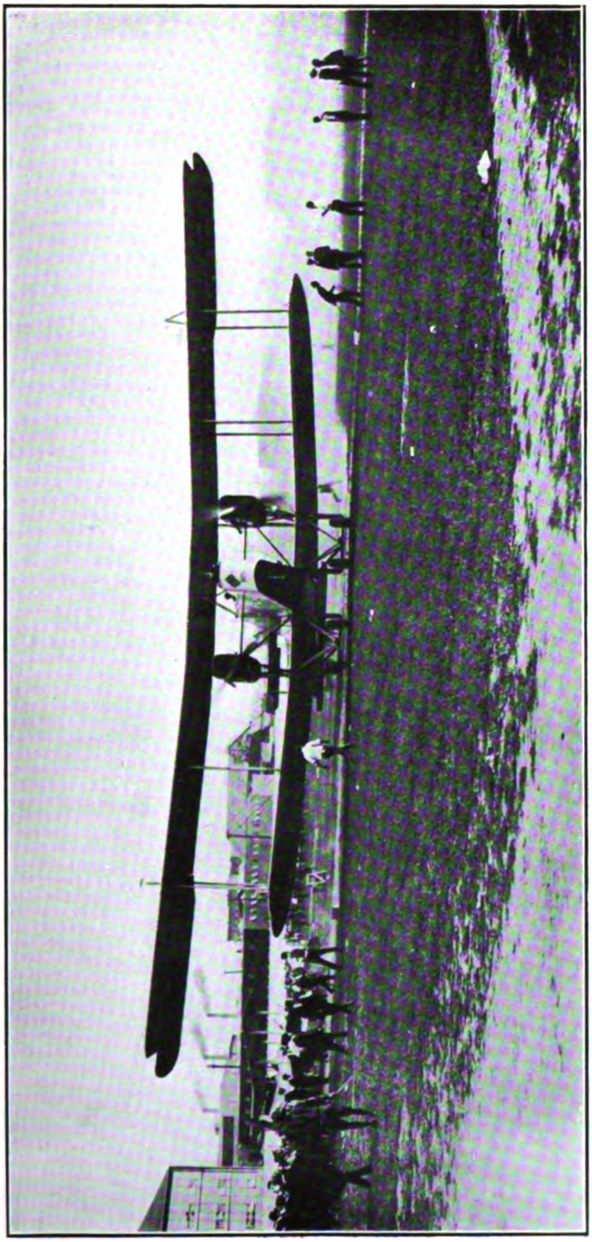


HANDLEY-PAGE BOMBING PLANE—TWO LIBERTY ENGINES

[SQUIER]

of Ordnance all necessary data for the determination of ballistic wind which, in view of the development of high angle fire, has become altogether indispensable for the construction of range tables needed for obtaining accuracy in the work of the artillery.

In carrying out the third element of the program, twenty-six meteorological stations were established, placed at carefully selected points over the whole of the United States, which stations have been manned by trained observers who telegraph to Washington each day observations on wind velocities at all altitudes up to 35,000 feet. In one instance these observations have been carried to 65,000 feet. On the basis of these observations, a daily forecast of upper-air winds is now being issued. The use which such forecasts may serve, both in connection with the aviation mail service and ultimately with the trans-atlantic service, may be seen from the fact that above the level of 10,000 feet, 95 per cent of the winds in both the United States and Europe are from West to East and often attain velocities in excess of 100 miles an hour. On November 6, 1918, at Chattanooga, Tennessee, a velocity of 154 miles an hour at an altitude of 28,000 feet was observed. It is because of this easterly direction of these upper air currents that all of the long flights thus far made have been from West to East. The importance of a forecast of such currents for the purpose of long flights will be appreciated as soon as the foregoing facts are understood. An airplane capable of a velocity of 154 miles an hour in still air either would remain stationary or travel at 308 miles an hour depending on whether it was headed into or with a wind of the velocity of that observed at Chattanooga.

All of the aerological work so far mentioned has been done with the aid of theodolites especially designed by Major W. R. Blair for this service. Sixty of these have been built for the work in this country and twenty shipped abroad.

The problem of exploring the upper-air currents over the Atlantic was at first thought insoluble on account of the absence of fixed bases, but the Meterological Service has developed propaganda balloons which already have flown at an average altitude of 18,000 feet from Omaha to New Jersey, a distance of more than a thousand miles. The success of the project now has made possible the mapping of the upper-air highways across the Atlantic; for arrangements are being made to send up from both coastal stations and from transatlantic steamers, these long-range balloons designed for from two to three-thousand-mile flights, and adjusted to maintain a constant altitude and to drop in Western Europe their records of average winds in these heretofore unchartable regions. The importance of this work for the future of aviation needs no emphasis.

The success which the Meteorological Service has attained would have been wholly impossible had it not been for the intimate and effective cooperation which has been extended to it in all of its projects by Director C. F. Marvin and the entire staff of the United States Weather Bureau.

VII—Physiological Study of the Flier

UNTIL a year and a half ago, interest centered in the development of aircraft and not in the flier. There was little regard for the special fitness of the man on the day and hour he drove his machine.

This was true, not only in the United States, but also in the Allied countries. The pilot was not selected because of any peculiar fitness for flying. It simply was a question of whether or not he had the nerve.

But, about the time the United States entered the war, it became clear that the science of physiology could be applied with advantage to the selection, classification and maintenance of the aviator. Each of the countries in the war now has a fully established air medical service, as an integral part of the air forces. In the British Army there is a separate air medical service with a Surgeon General of Aeronautics. In the American Army this work has been handled effectively by a division of the Surgeon General's office, assigned as part of the Air Service.

The early view that any one who "had the nerve" could fly caused enormous avoidable wastage of life and material. The lesson learned from bitter experience was that it is essential to obtain fliers who are especially fitted for particular work and to keep them in condition to perform their duties at all times.

Nature never intended man to fly in the same sense that she did not intend him for life in a submarine. Conditions are unnatural from the time he leaves the ground until he returns. There are many obstacles to overcome. He flies in an atmosphere deficient in that oxygen which is the "breath of life;" he is subjected in war to the shells of anti-aircraft guns and enemy aircraft; he travels through space high above the ground at rates well in excess of 100 miles an hour. In attaining altitudes and breathing rarefied air, the flier is defying nature.

The pilot is the heart and brain of the whole flying apparatus. Parts of the airplane may break without serious result, but when the pilot breaks, even momentarily, nothing is left to direct the flight. The man and the machine come crashing to the earth.

All this the Air Medical Service had to consider. The service had the advantage of a series of reports of the air medical services of our Allies, which enabled it to attain self-footing in a remarkably brief time. A medical research laboratory, fully equipped, was established by the Army Air Service at the flying fields on Long Island, N. Y.

The keynote of the American Air Medical Service is the handling of the flier as an individual, which naturally brings the work into three main divisions:

First, the selection of the flier:

Second, the classification of the flier, and

Third, the maintenance of the physical efficiency of the flier.

THE SELECTION OF THE FLIER

The outset of the war made it necessary to obtain a large number of military aviators in the shortest possible space of time. The medical problem consisted of selecting men who were physically fit.

It is possible for men to fly in spite of one or more physical handicaps, such as having only one leg or one eye or even being cross-eyed, but such men are not desirable fliers, since men with complete endowments naturally have superior advantages. The man in the flying service would be called upon to negotiate critical emergencies in the air. Instant decision and action, therefore, would be essential for success. So it was seen that only those men with exceptional mental and physical capabilities should be chosen.

In order to accomplish the best results, a comprehensive program was undertaken, providing for the standardization of both tests and examiners. Sixty-seven military units were established, each examining from ten to sixty applicants a day. The figures show that 70.7 per cent of the applicants were qualified. The large number of applicants made it possible to maintain the highest standard in selecting men.

In the same spirit with which the United States determined to supply the American air fighters with as good, if not better, planes than those used by the enemy, it was decided that the American aviators must be as good if not better than those of the enemy. The outcome of any encounter might easily depend upon which combatant possessed the better vision and other special senses, the better nervous system, and the better mental and physical equipment in general.

Each applicant received a complete physical examination embracing all the features ordinarily required of men entering the military service, and, in addition, comprehensive and extensive tests of the special senses of vision, hearing and motion sensing.

CLASSIFICATION OF THE FLIER

It is important to classify the flier for the kind of work he is physically capable of performing. Some men are not able to fly at higher levels than a few thousand feet without serious deleterious effects, while others may operate at much higher altitudes. It is necessary to know a flier's limitations before his training is specialized, for the saving of time and money, and, in fact, the flier himself. It would be an evident waste to train a pilot for combat work and then find he was physically capable of doing only bombing at a relatively low level. To accomplish this classification, branch medical research laboratories were placed in the flying fields, which by appropriate tests on the rebreather machine, developed at the parent institution at Mineola, classified the fliers.

The work of these laboratories demonstrated that sixty-one per cent are capable of flying to 20,000 feet or more, twenty-five per cent should not fly above 15,000 feet, and fourteen per cent were unsafe above 8,000 feet.

The re-breather is used also to determine temporary unfitness for altitudes, due to some intercurrent illness, dietary indiscretion and staleness from prolonged flying.

The necessity for altitude classification is readily understood from the fact that whereas in 1915 flying rarely exceeded 8000 or 10,000 feet, through improved design, scouts of today climb to altitudes of 25,000 feet within a very short time.

Night bombing is carried out at altitudes as low as 300 feet. Day bombing, in order not to reveal the objective of the flight and to guard against concentrated anti-aircraft fire, may call for flights at extremely high altitudes. Reconnaissance machines rarely get to high altitudes, owing to the necessity for more or less close observation of the ground, and machines doing this work accomplish low flying even in the face of highly concentrated anti-aircraft fire, and other enemy activity. Machines cooperating with the artillery making range corrections for batteries, do not often work above 6000 or 8000 feet.

Owing to the fact that all this work is widely diversified, it is essential that each man be placed in that division for which he is best suited. A knowledge of the limitations of a valuable man spells increased efficiency. Just as the pilot is provided with a certain type of plane adapted to the work in hand, so the plane must be provided with a pilot adapted to the work.

Fliers who are forced to undergo abrupt changes in atmospheric pressure and oxygen supply must be singled out. Atmospheric pressure plays an unimportant role; the whole problem resolves itself into a deprivation of the normal oxygen supply.

The Flack bag was the prototype of the rebreathing apparatus which has been developed in the medical research laboratory. By means of this apparatus the aviator rebreathes air confined in a tank, from which he gradually consumes the oxygen. As the percentage of oxygen decreases, the flier, in effect, is slowly ascending to higher altitudes. In the course of twenty-five to thirty minutes he lowers the oxygen content of the air in this tank to 8 or 7 per cent, which is equivalent to attaining altitudes of 25,000 to 28,000 feet.

Another means of attaining the same result is by the diluting apparatus, which supplies directly to a mask over the face a mixture of air and nitrogen in whatever proportion is desired. All of these tests have been standardized and confirmed by the low-pressure tank, in which the air is rarefied to correspond to any given altitude.

By a comparison of the percentage of oxygen to which the flier succumbs when on the low-oxygen test, it is possible to determine the altitude at which he would fail were he in the air. This determination is made on the ground, without danger either to the flier or to his machine.

The effect of low oxygen upon the mental processes varies greatly in the individual. He usually becomes mentally inefficient at an altitude at which there is as yet no serious failure of his vital bodily functions. By simple tests of mental alertness during rebreathing it is easy to determine that one flier becomes mentally inefficient at 15,000 feet, in sharp contrast to another who has his full mental powers up to and beyond an altitude of 25,000 feet.

Oxygen-want exaggerates any latent defect of the eyes. Crash reports have demonstrated that a large proportion are due to eye defects.

"Stunting" essentially is an internal-ear problem. During and after rapid turning the flier's brain is receiving impulses from his semicircular canals. In a normal individual nothing can control or alter the sending or receiving of these impulses, which produce sensations of motion. Fliers vary greatly in their ability to interpret correctly the significance of these impulses. Experience alone enables them to familiarize themselves with their meaning. Those who develop the greatest ability in their interpretation naturally fall into the scout-pursuit class. Those who, in spite of training, are still disturbed or bewildered by stunting are reserved exclusively for straight flying.

THE MAINTENANCE OF EFFICIENCY

When the work of selection and classification is completed, the great problem of the Air Medical Service is to maintain the fliers on a basis of high physical efficiency.

After a certain amount of continuous service the flier begins to show unmistakable signs of deterioration. Until the Air Medical Service went to work, fliers were permitted to continue until they broke. Their breaking was signalized sometimes by simple failure to return from behind the enemy lines; sometimes by becoming mentally and nervously exhausted to the extent of permanently unfitting them for flying.

The rebreathing test also is valuable in determining this staleness in fliers, caused by frequent exposure to high altitudes. Incipient cases of the deterioration of efficiency caused by oxygen-want are detected easily by means of the rebreather. Then it is possible to ground a man for a certain period to enable him to recover entirely, whereas if this condition were not detected, it might progress to a point where it would be impossible for the man to regain his former efficiency. When staleness becomes marked the flier is liable to faint in the air, thus losing his life and wrecking his machine. Periodical examinations are made to detect staleness.

There are three and only three means by which the flier's usefulness may be terminated; first, by the enemy; second, by the failure of the machine; and third, by the failure of the flier himself.

While it was not possible to arrive at exact percentages, estimates made at the time of our entrance into the war, based upon information from Italy, France and Great Britain, indicated that not more than two per cent. of the aviation losses in active service were caused by the enemy. Failures of the airplane were responsible for only slight losses, due, of course, to the rigid inspection of the machines. Statements from all sources agreed that of the total number of fliers permanently out of the flying service, not more than 8 per cent could be attributed to mechanical shortcomings of the airplane or engine.

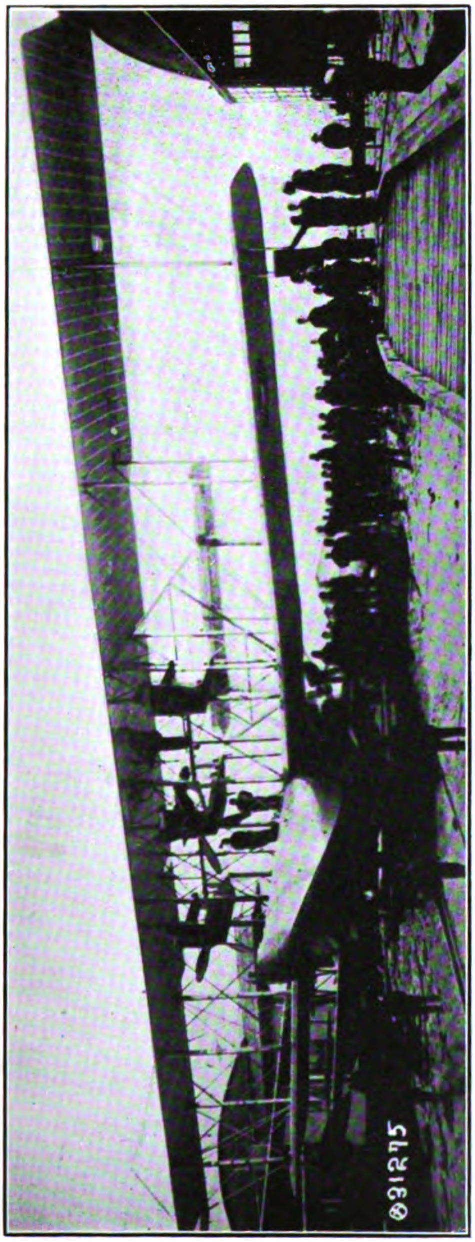
The remaining 90 per cent loomed large when it was realized that this proportion represented trouble in the flier himself.

Therefore the "Flight Surgeon" was authorized to keep aviators physically fit and to study the causes of accidents attributed to the failure of the man.

Keeping the flier fit embraces the amount of physical exercise necessary; the provision of proper recreation; the state of fatigue of the individual; the amount of sleep; the provisions for leave or furlough; the food problems; the field conditions bearing on his welfare, and his reexamination at frequent intervals.

It was observed that more than half the injuries in crashes were caused by the flier striking his head against the cowl. The cowl was cut out to give the flier more room in front, and this change has practically eliminated the head injuries. A safety belt was lashed to the machine by a simple rubber shock absorber, and since this has been done the number and extent of injuries to the upper abdomen and ribs have been reduced decidedly. The problem of protecting the flier against the extreme cold of high altitudes in winter was solved by designing electrically warmed clothing. The problem of enabling the flier to withstand the glare reflected sunlight above cloud banks was solved by furnishing him with the "Noviol" type of goggles. The Dreyer oxygen apparatus is used to compensate for his lack of sufficient oxygen in high altitudes. This apparatus has been so modified and perfected that it is now possible to automatically supply a flier with the correct amount of oxygen for the altitude at which he is flying.

All this has been done toward reducing this "ninety per cent," and much more is being developed. Within the last few months an apparatus has been perfected whereby students may acquire flying experience and training without leaving the ground. This machine, known as the Ruggles Orientator, is a modification of the universal joint, composed of three concentric rings so pivoted as to permit the fuselage, which is pivoted within the innermost ring, to be put through every possible evolution experienced in actual flying, except forward progression.



N. C. 1 NAVY SEAPLANE (OR FLYING BOAT)—THREE LIBERTY ENGINES

[SQUIER]

An analysis of "crash reports" shows that a large number are due solely to failure to come out of the spinning nose dive or tail spin. The student failed in these maneuvers because he had not learned to compensate by sufficient previous experience for his dizziness. The new apparatus gives the flier experience until he becomes familiar with the various sensations.

Another method of educating the student is by means of flying calisthenics. By daily turning and tumbling exercises he becomes accustomed to positions and movements in which at first he is awkward and bewildered.

It has become evident during the last nine months through activities of nutritional survey parties of the Food Division, Surgeon General's Office, that there is a great need in each aviation camp for a nutrition officer. The nervous system is more highly differentiated than the muscular system, and more easily upset by improper food. It has been shown that a nutrition officer with special knowledge of food values should supervise the messes of all cadets and officer fliers in order to keep up efficiency.

Under date of November 20, 1918, General Pershing says in a report to the Secretary of War: "Our aviators have no equals in daring or in fighting ability, and have left a record of courageous deeds that will ever remain a brilliant page in the annals of our Army."

The work of the Air Service Division of the Surgeon General's Office was instituted by Major, now Brigadier General T. C. Lyster, with the assistance of such specialists as Colonel George H. Crabtree, Colonel William H. Wilmer, Lt. Col. E. G. Seibert, Lt. Col. Isaac H. Jones, Lt. Col. Eugene R. Lewis, and Lt. Col. Ralph H. Goldthwaite.

VIII—Activities of the Bureau of Standards for the Air Service

RADIO INVESTIGATIONS

A THOROUGH study of vacuum tubes for use in transmitting, receiving, and amplifying is in progress; a study of insulating materials used in radio apparatus; the development of a permanent contact crystal detector; the development of a high-frequency oscillographic equipment; the furnishing of standards for use in radio development are among the subjects handled in connection with the production of radio apparatus for military purposes.

The facilities of the laboratory and working quarters have been provided for the Research Laboratory of the Science and Research Division of the Signal Corps, and the Intelligence Division of the Signal Corps.

AERODYNAMIC INVESTIGATIONS

The wind tunnel of the Bureau of Standards has been employed in a wide variety of military problems, among which may be mentioned the following:

Bomb-dropping devices have been tested and compared. The head resistance and other characteristics of airplane bombs have been measured in order to provide data for computing the trajectories. Machine gun sights for airplane use, with automatic adjustments for speed have been tested and adjusted in the wind tunnel. Hundreds of Pitot tubes and Pitot-Venturi combinations for measuring the speed of the airplane have been calibrated. The head resistance of many types of engine-radiator sections has been measured. Small variable-pitch propellers for driving at constant speed the generator used in radio signaling, independently of the speed of the airplane or engine were perfected through wind tunnel tests and later tested in large numbers. Finally, the characteristics of new wing-sections and new airplane designs have been determined from wind tunnel tests on models.

AERONAUTIC POWER PLANTS

An altitude laboratory for the study of airplane engine characteristics and performance at all flying altitudes was begun in August, 1917, completed in January, 1918, and has been in service since that time.

Studies have been made of the Liberty "8" and Liberty "12", Hispano Suiza 150 h. p., Hispano-Suiza 180 h. p., and Hispano-Suiza 300 h. p. models.

The results include complete data as to the power developed, fuel consumptions and heat balances at all practicable engine speeds and altitudes up to 30,000 feet; the demonstration of causes of bad carburetion at high altitudes and of the requirements for the best results, together with the development of means for producing these results automatically; the analysis of the effect of fuel composition on engine performance, the results of which served as the basis of specifications for aviation gasolines; the securing of necessary data for the establishment of standard flight test specifications for engines, including variations of horse power with the pressure, density and temperature of the air supplied the carburetor; the measurements of the effect of different compression ratios on engine power at different altitudes; the increase in power possible when using supercharging devices designed to supply the engine with air at pressures greater than that at which the airplane is flying.

Airplane Radiators

The necessary apparatus has been designed and constructed to study the heat transfer characteristics of radiator cores used in airplanes. The performance of more than 85 different types of cores has been studied in this apparatus at reduced pressure and high rates of air flow. Head resistance measurements have been made on these cores in the 54-inch wind tunnel. The results of these experiments have shown that certain types of cores in use today may absorb twice or three times as much of the engine power as other types and as much as 25 per cent of the total power developed by the engine.

Experiments on the head resistance of a model fuselage fitted with a nose radiator have shown that the power absorbed by the resistance of a nose radiator may be as much as 40 per cent greater than that absorbed by a radiator more suitably placed. To afford maximum efficiency, a radiator must be designed for its particular air speed and position on the airplane. The results of this investigation give the necessary data for the design or selection of radiators for all air speeds and for various locations.

IGNITION PROBLEMS

Investigations have been made on various problems connected with spark plugs and other ignition apparatus used on airplane engines. This work has resulted in the development of a new porcelain for spark plug insulators which is definitely superior electrically and mechanically to any previous commercial product. Methods of test for spark plugs have been developed as a basis for Bureau of Aircraft Production specifications and several thousand spark plugs have been tested by these methods. The results have led to the use for aviation work of several high-grade commercial porcelains not previously considered for this purpose.

CARBURETION

In the carburetor testing plant the work has included a detail study of the changes in mixture proportions that occur with throttle manipulation under the conditions of atmospheric pressure and temperature existing at and between ground level and 33,000 feet altitude. This work has resulted in the development of suitable control of the mixture under throttle manipulation at any level above the earth's surface; and in the development of methods and devices for automatic correction of the variations in mixture proportions ordinarily occurring in passing from ground level to an altitude of 33,000 feet.

LIGHT ALLOYS

An important group of problems which engaged the attention of the Bureau was that relating to the production of light aluminum alloys and the improvement of their mechanical properties. Thus, new manufacturing methods were developed for a well-known rolling and forging alloy by which both the ease of its production was increased and its physical properties improved. Studies were made of the corrodibility of various alloys, while mechanical and metallurgical tests were made of a variety of different compositions of alloys giving most valuable information for the guidance of the designer of engines and planes.

A light alloys committee was organized to act as a clearing house for information along these lines and to oversee and direct the research work proceeding throughout the country.

AIRPLANE DOPES AND VARNISHES

Specifications for acetate and nitrate dopes were prepared at the Bureau with the cooperation of dope manufacturers, airplane constructors, and representatives of the government. Simultaneously, dopes manufactured in the country were examined in accordance with the specifications and list of products prepared which were approved for use on government aircraft. After much controversy, the use of acetate dopes containing tetrachlorethane was forbidden because of the toxicity of the above compound. Many proposed methods of fireproofing dopes and fabrics have also been examined. A commerical method of preparing and stabilizing lactic acid esters was devised for use in acetate dopes, in order to conserve the products of acetate of lime. A transparent silk fabric for possible use in obtaining low visibility has recently been perfected. Lately work has been in progress on the pigmentation of dopes with a view to protecting the dope film from the deteriorating action of sunlight, and thus prolonging its life, at the same time dispensing with the use of enamels, thus saving one step in production. The use of pigmented dopes will also conserve cellulose acetate.

Investigations of methods of making wooden parts of airplanes water resistant showed that a good grade of spar varnish was satisfactory, and a specification for such a varnish that could be produced at low cost was prepared. The same varnish has been found to be a satisfactory coating for doped linen or cotton, used either as a transparent varnish or as the basis of a vehicle for pigmented coatings. These may be used on both wood and metal.

AIRPLANE FABRICS

Previous to 1916 linen fabric was used exclusively in the covering of airplane wings and found to be satisfactory in every respect. During the present crisis, it became evident that the available supply of linen would not suffice for the demands of the military programs of the Allies, and it became necessary to find a material which would form a satisfactory substitute for linen. The urgency was emphasized by the conditions in Russia, from which the larger portion of the flax formerly had been derived.

As early as January, 1916, the Bureau started investigating the possibilities of substituting cotton for linen airplane fabric and found that the general consensus of opinion among manufacturers and investigators here and abroad was that cotton fabric could not be used for wing coverings. Their difficulties were due to the fact that they attempted to substitute structure of fabric rather than physical properties. The linen fiber has radically different properties from the cotton fiber, and the only hope for successful cotton airplane fabrics was so to change their structure that the ultimate fabric had the same properties as the linen fabric.

The investigation was confined to the study of stresses and stress distribution in fabrics, together with the factors covering the properties of cotton fabric as related to wing covering.

This phase of cotton manufacturing was an entirely new one, and great difficulty was experienced in studying the manufacture from a new angle, on account of the limited time available. Upon the entrance of this country into the war all the facilities of the manufacturers were made available to the Bureau's experts.

In March, 1917, the Bureau was in a position to issue instructions covering the construction of cotton fabrics, some of which proved quite successful. The next important step was to determine the actual performance of these fabrics and to this end samples were placed on Army planes at Langley Field and Navy planes at Pensacola during August, 1917. Later these fabrics were placed on planes manufactured by the Canadian Aeroplane Company of Toronto about the middle of October, 1917, in all cases with the most satisfactory results.

The Grade A cotton fabric now being supplied to the Air Service compares favorably with the linen regarding weight, has a much higher factor of safety, a greater tear resistance, and dopes up to satisfactory tautness. The life of any fabric is dependent entirely upon the life of the dope, and therefore the cotton has as long a life as the linen.

The English Government became concerned about its linen supply, and also adopted the fabrics designed by the Bureau.

As a result of more recent investigations by the Bureau of Standards, another distinct fabric has been evolved which is 25 per cent lighter than any linen fabric now in use, and is materially stronger.

Director S. W. Stratton has placed the services of the entire Bureau of Standard's staff at all times at the disposal of the Air Services of both the Army and Navy in attacking and solving new problems which have constantly been presented, and in fact the Bureau has been during the war practically an adjunct of the War and Navy Departments.

IX—National Advisory Committee for Aeronautics

THE National Advisory Committee for Aeronautics was established by Congress by Act approved March 3, 1915. Under the law the Committee is charged with the supervision and direction of the scientific study of the problems of flight with a view to their practical solution, the determination of the problems which should be experimentally attacked, their investigation and application to practical questions of aeronautics. The Committee is also authorized to direct and conduct research and experiment in aeronautics in such laboratory or laboratories, in whole or in part, as may be placed under its direction.

In addition to its specific duties, the Committee has acted as a clearing house for inventions submitted to the War and Navy Departments with a view to their possible usefulness in the field of aeronautics. These inventions have been studied carefully by the Committee's technical staff and those deemed worthy of development have been called to the attention of the Military branches of the Government. During the last year, the Committee has examined approximately seven thousand such inventions and suggestions.

The Committee is recognized by the Aircraft industry as an authoritative source of technical information and as a court of arbitration whose weighed judgment obtains. The National Advisory Committee for Aeronautics is today the only official agency for the development of aeronautics which numbers among its members officers of both the Army and the Navy thus assisting in the coordination of the air activities of these services.

The scope of activity for aeronautical research to be carried out by the Committee in the future has been outlined to include the following investigations:

1. Propellers; 2. Aerofoils, or elementary supporting and controlling surfaces; 3. Combinations of supporting and controlling surfaces; 4. Reaction between the airplane and the propeller system; 5. Structure; 6. Investigations to improve the present instruments for use in airplanes and to develop new instruments to meet future needs; 7. In connection with aviation engines, the problem of supercharging to maintain power at different altitudes; 8. Improvement of engine details, radiation, carburetors, ignition, and fuels and lubricants;

9. Standardization and investigation of materials for aircraft construction; 10. Free flight tests; 11. The study of the relation of the atmosphere to aeronautics.

Some of the more important reports rendered during the last year are:

1. Behavior of Airplanes in Gusts. 2. General Theory of the Blade Screw. 3. The Testing of Balloon Fabrics. 4. Aluminum and its Light Alloys. 5. Carbureting Conditions Characteristic of Aircraft Engines. 6. General Analysis of Airplane Radiator Problems. 7. Effect of Compression Ratio, Pressure, Temperature, and Humidity on Power. 8. Properties and Preparation of Ceramic Insulators for Spark Plugs. 9. Heat Energy of Various Ignition Sparks. 10. A New Process for the Production of Aircraft Engine Fuels.

With the completion of the Committee's aeronautical laboratory at Langley Field, the Army Experimental Air Station, the work of aeronautical research will be expanded, it is hoped, to cover present and future problems vital to the Science and Art of Aeronautics.

The National Advisory Committee for Aeronautics gave valuable service to the Army and Navy both before and especially during the early months of the war. This body of selected men, reporting directly to the Congress, furnished to the Chief Signal Officer a medium for counsel and advice. This Committee inaugurated and recommended the establishment of the Aircraft Board. Prior to the establishment of the Aircraft Board, the Chief Signal Officer enjoyed the counsel of the Advisory Committee which was always ready to assemble without regard to time or place.

Although the statute creating this Committee contemplated a general supervision of aeronautical research, all manner of questions were submitted to its deliberation and judgment during the early period of the war. Whether it was the founding of a permanent aeronautical experimental station which should be a sort of West Point for aeronautics, the assembling of University Presidents to establish curricula for our ground schools, or the search for a practical solution to the stifling situation confronting the Government as a result of the airplane patent controversy, the National Advisory Committee was at all times available to the Army and Navy authorities for counsel and decisions.

PLATE IX.
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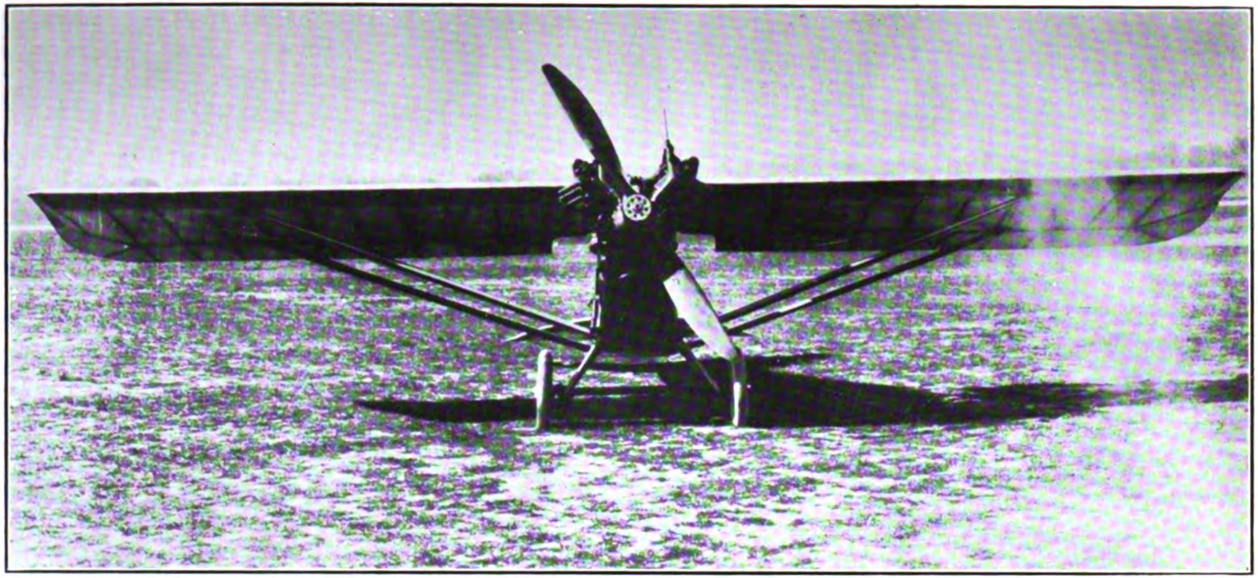
VOL. XXXVIII, NO. 2



Leoning Monoplane—300 H. P. Hispana-Suiza Engine

[Squier]

X—Work of the Science and Research Division of the Signal Corps

THE Science and Research Division of the Signal Corps was established by order of the Chief Signal Officer on October 22, 1917, and Lieut. Colonel R. A. Millikan placed at its head.

Its personnel, exclusive of the Meteorological Section, consisted on November 11, 1918, of twenty-one commissioned officers, 118 enlisted men, and sixteen civilian employes of scientific and technical qualifications. Four of these officers are abroad and seventeen in the United States.

At the time of the signing of the armistice, the Science and Research Division had in progress sixty-four problems.

A summary of the most important results actually achieved up to that time is given herewith:

1. The Aeronautic Instruments Section, in addition to fulfilling the function specifically assigned to it of writing all the initial specifications for aeronautical instruments in use on planes, and in working continually with the instruments in production in order to detect imperfections and make suggestions for improvement, designed and developed wholly within its organization, through the activity of its chief, Major C. E. Mendenhall, a new and improved Pitot-Venturi tube for use in the determinations of airplane air speed. This instrument was actually put into production and thirty-seven thousand ordered.

2. Major Mendenhall and Lieut. R. C. Williamson have cooperated with the General Electric Company in the development of a new and improved compass, ten thousand of which were produced. This compass is now in use on planes for the American Army.

3. The Science & Research Division cooperated with the Eastman Kodak Company in the development of an entirely new film camera which is in production and which is the only film camera in existence capable of taking the standard size 18 by 24-cm. pictures. This camera is entirely automatic and capable of taking one hundred pictures without refilling.

4. The Science and Research Division with the assistance of the Burke & James Company of Chicago developed a new plate camera which is a modification of the French De Ram. It is

semi-automatic, carrying fifty plates. It has been accepted and is in production now. Both this photographic development and the one mentioned under (3) were made possible solely by the bringing together of a highly trained scientific group in the Photographic Section of the Science & Research Division.

There would have been practically no possibility of the attainment of these results without such a group. This photographic group constituted one of the Sections of the Science & Research Division until about July 1, 1918, when it was transferred to the Production Division. The development of photography during the present war, due to the advent of the airplane has placed it permanently among the indispensable agencies for successful military operations. The older methods of recording personal observations have been superseded entirely by the far more accurate and reliable photographic record. A complete detailed photographic map must now be made daily of each sector immediately in front of an army, and by carefully matching these maps and by intensive study of each individual area, the maze of trenches, entanglements, machine-gun nests and shell-holes can be accurately analyzed. It is worthy of notice that 17,000 photographs were taken by the British army before the operations at St. Quentin in order that a relief map of the sector might be made before the drive against the Germans. By means of this map, every detail of the work to be performed by the British troops was planned. By a series of consecutive photographs taken at regular intervals by a moving-picture camera an accurate and reliable picture of a military road, for instance, showing all details to scale may now be made in a few minutes. With the aid of the camera the detection of camouflage is possible where the human eye would fail. This highly specialized photographic work has now taken its permanent place in the waging of modern warfare.

5. Dr. Gordon S. Fulcher, working in collaboration with the Miller Rubber Company, developed a leak proof tank simultaneously with the development of a similar tank in England—achievements of the utmost importance for the lives of Allied aviators. The Fulcher Tank was ordered placed upon all fighting planes.

6. Major C. E. Mendenhall and Lieut. John T. Tate, with the assistance of the General Electric Company, perfected a trench signalling lamp which, after test at the front, was

ordered sent over in considerable numbers and will probably constitute a standard American projector for the United States Army.

7. Major R. W. Wood developed a telescopic signaling device using a six-volt, two-ampere lamp. This lamp was tested at the front and favorably passed upon by the A.E.F. It has made possible light signaling in broad daylight over a distance of eighteen miles. General Pershing ordered a considerable number of these sent to the A.E.F.

8. Major Wood also developed a secret daylight signaling lamp which has a range of five miles. This also was ready for shipment abroad at the time of the signing of the armistice.

9. Secret signaling at night, with the aid of ultra-violet light, was perfected by this department, working in collaboration with Mr. Norman Marshall. With simple signaling telescopes of the sort mentioned above, using only a six-volt, two-ampere lamp, secret signals have easily been sent six miles. Major Wood also developed new means of adapting this method to the problems of signaling to airplanes, and secret signaling between convoys, and obtained thereby a device which will be of much use in peace as well as in war.

10. W. J. Lester, S. R. Williams, Capt B. J. Sherry and Sergt. W. H. Redman of this Department developed propaganda balloons which have a range of more than a thousand miles. This is an accomplishment which is invaluable to the future development of aviation, particularly with reference to transatlantic flights, whether in peace or in war.

11. Dr. W. F. G. Swann and Dr. Gordon S. Fulcher of the Science and Research Division gave invaluable service to the Balloon Section by making an elaborate and highly important study of the causes of fires in balloons and sending to the balloon officers in the Balloon Section directions for the prevention of such fires.

12. Dr. H. N. Russell of the Science and Research Division and Capt. J. P. Ault developed means for navigating airplanes with the aid of the sextant and an artificial horizon. They also developed means of speedy reduction of observations so that an observer in a plane can locate himself with an average error of not more than ten nautical miles within five minutes after he makes his observation. This achievement is of great value for the problem of long flights.

13. Lieut. John T. Tate and Otto Mohr developed a port-

able landing light for use on aviation fields. This device was officially tested and favorably reported upon by the division of Military Aeronautics. It is now in use at some fields and recommendation has been made by the Division of Military Aeronautics that two complete units be made a part of the permanent equipment of all aviation fields.

14. Dr. Harvey N. Davis of this Division represented the army in the development of the helium program and contributed in a large measure to the great success which has been attained in that work.

15. The Chemical Section under Dr. H. D. Gibbs developed new methods of producing acetone, which will make it possible to obtain this substance for one-fourth the price which the Government is now paying.

16. The Chemical Section, through the activity and energy of Dr. L. E. Wise, developed sensitizing dyes which previously had not been obtainable at all in the United States and which were urgently needed in airplane photography.

17. Capt. Herbert E. Ives and Dr. F. A. Saunders of this Department, in collaboration with I. W. Priest of the Bureau of Standards, made notable contributions in the development of color filters for detecting camouflage and increasing visibility. Forty thousand of these devices now are in use in the Army and Navy.

18. Dr. Wilmer A. Duff's Section worked out the only method which has been developed thus far for the accurate, experimental determination of bomb-trajectories. This is of primary importance in obtaining precision in bombing. It will have peace uses as well as war uses.

19. Dr. Duff's section also developed a bombsight stabilizer which has reduced the main error now made in bombing, namely, the error in the determination of the vertical, by more than three-fold. When it is remembered that a three-fold increase in the accuracy of bombing is precisely equivalent to the multiplication by three of the production of bombing planes, the importance of work of this kind scarcely needs comment.

There are probably a dozen of the nineteen developments mentioned above, each one of which is worth more to this country than the total amount spent upon the establishment and maintenance of the Science and Research Division from its inception up to the present time.

XI—Radio Development Work

IN the question of the engineering achievements of the Signal Corps during the war, the development of radio apparatus forms a large part. Inasmuch as the vacuum tube occupies so prominent a role in almost every kind of radio apparatus, an outline of its development logically precedes discussion of the radio sets.

VACUUM TUBES

The application to radio inter-communication of the vacuum tube—perhaps more properly called the thermionic tube or bulb—is one of the most interesting developments in the whole field of applied science. For not only has it made possible what has been justly heralded as one of the most spectacular achievements of the whole war—the airplane radiophone— but the confidence growing out of the extensive experience with the vacuum tube in warfare, coupled with its extreme adaptability, have resulted in a rapidly increasing amount of radio development involving its use.

PRE-WAR HISTORY

The vacuum tube was known in various forms before the war. Following extensive experiments with the so-called "Edison effect", Fleming, some years ago, produced the well known Fleming valve—a current rectifying device, capable therefore of being used as a detector of radio signals. This device contains two elements: an incandescent filament emitting electrons, and a plate upon which an alternating voltage is impressed, both placed within an evacuated bulb. Later Dr. Lee DeForest introduced an important modification by placing a wire mesh or "grid" between the filament and the plate. A small voltage variation on this grid produces the same current change through the tube as would a much larger voltage variation on the plate, thus adding amplifying properties to the detector characteristics of the Fleming valve. DeForest called his device the "audion". Later, with superior facilities for evacuation available and with a more intimate knowledge of the laws of thermionic emission from hot bodies, improvements and modifications were made in the audion or vacuum tube by both the General Electric Company and the Western Electric

Company, the latter designating their product as "vacuum tube", and the former the "pliotron".

In addition to acting as detectors and amplifiers, as mentioned above, vacuum tubes can function in two other important ways:

> 1. As Oscillators. In properly designed circuits containing inductance and capacity they will act as radio frequency generators, for use in transmitting or receiving radio signals.
>
> 2. As Modulators. By suitable connection to an oscillator circuit or antenna, they can be made to vary the power radiated so that the envelopes of the waves transmitted shall have any desired wave form, as for example, the speech waves from an ordinary telephone transmitter.

The most striking use made of vacuum tubes prior to the time we entered the war was the transmission of speech by radio from Washington to Paris and Honolulu, during the experiments carried out by the American Telephone and Telegraph Company and the Navy Department. Vacuum tubes were used as the radio frequency generator for transmitting, and for detector and amplifier in receiving.

When the United States entered the war, vacuum tubes already were in use by the Allied forces for various signaling purposes. The French particularly had been quick to recognize the military value of vacuum tubes and had, previous to June, 1917, developed very creditable tubes and apparatus. In America, tubes were in limited use as "repeaters" on telephone lines, and as detectors and amplifiers in laboratories and radio stations. The total production, however, in this country did not exceed three or four hundred a week.

DEVELOPMENTS DURING THE WAR

Early in our participation in the war, it became evident that vacuum tubes would be required in very large quantities in order to meet the growing demands for radio communication and signaling. It was equally evident that service conditions, not hitherto anticipated, would require great mechanical strength, freedom from disturbance under extreme vibration, and uniformity of product sufficient to make possible absolute interchangeability of the tubes in sets, without the necessity of readjusting when changing tubes. To these conditions must be added that of minimum size consistent with dependable operation.

To make such a device, with its complicated, yet accurately constructed metallic system, within a practically perfect vaccum, is no small problem even when made in the laboratory, on the individual unit basis, by a skilled operator who appreciates the delicacy of the job. To turn out tubes by the thousands by factory methods involves almost infinitely greater difficulties. How well certain companies, in collaboration with the Signal Corps, have succeeded in solving these difficulties is indicated by the fact that recently the total rate of production in the United States of high quality standardized tubes was considerably in excess of one million a year. This rate of production could be made many times greater on short notice.

As an example of the difficulties which this quantity production has involved may be mentioned that of evacuation. The degree of vacuum required is such that unusual methods of exhaust are necessary. The heating of the tubes in electric ovens is supplemented by heating of the elements of the tube by excessive filament and plate electrical power input. Molecular pumps are employed, necessitating an extremely large number of pumps to handle quantity production. Special treatment of metal parts prior to assembly is employed to reduce the gas given off by them during the exhaust process.

Another problem is that of making the complicated metallic structure of all tubes exactly alike, in order to insure identical electrical properties. As an indication of progress in this direction, it may be stated that one company is prepared to manufacture, in quantity, a certain tube in which the clearance between filament and grid is only three hundredths of an inch, the allowable variation being of course only a small percentage of this.

Manufacturing in quantity involves careful inspection. The problem of specifying definitely the required performance of tubes, the development of adequate testing specifications, the placing of standardized testing and inspection methods, personnel, and equipment in the various factories so that tubes manufactured at different times and places would, after passing inspection, be uniform and interchangeable—these questions were entirely new and have been solved almost entirely by the Signal Corps Engineers.

PRESENT STATE OF THE ART

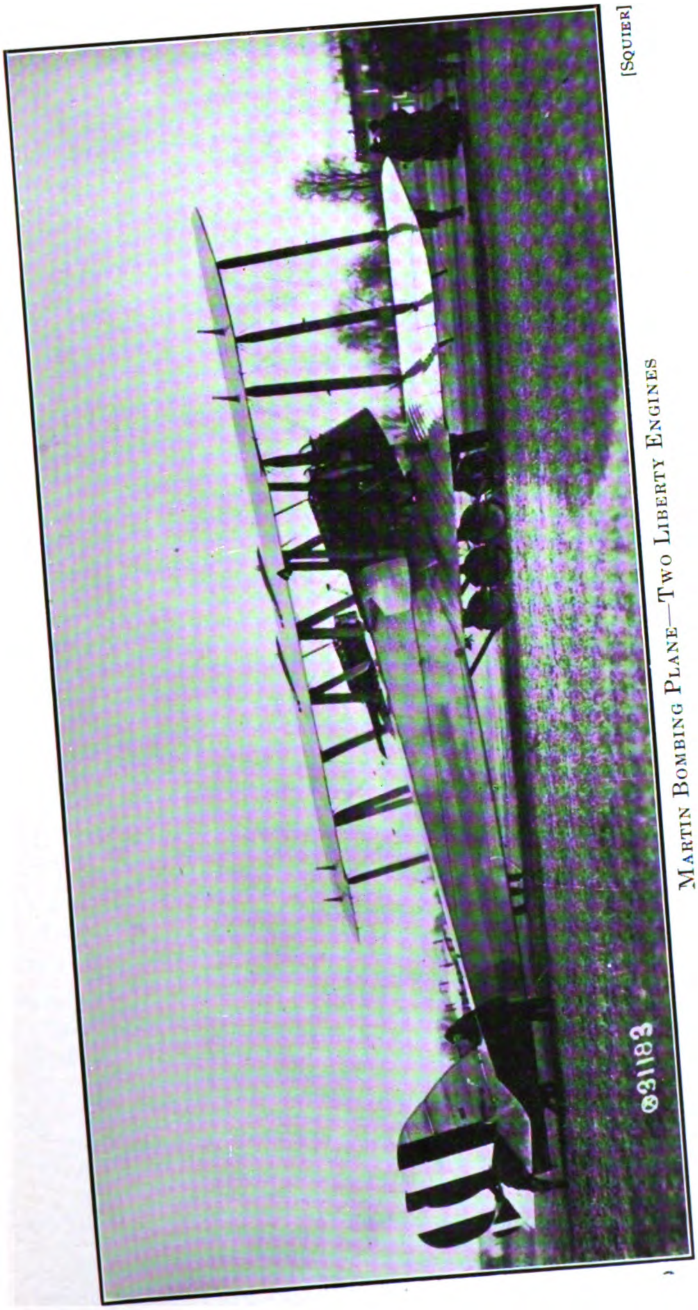
Tubes developed by the Signal Corps may be divided into two general classes: the tungsten filament types as developed and manufactured by the General Electric Company and the De Forest Radio Telephone and Telegraph Company, and the coated filament or Wehnelt Cathode types as developed and manufactured by the Western Electric Company. The coated filament tubes so far have proven superior to the tungsten filament tubes for Signal Corps use. Both classes have been standardized as regards base, exterior dimensions, filament current and voltage, and in addition, plate voltage and output for transmitting tubes; and amplifying power and detecting power for receiving tubes. Except in certain special cases, the Signal Corps uses two types of tubes, one for transmitting, and another for receiving. The French and the British have been using one type for both transmitting and receiving, but present tendencies of the British are toward different tubes for different duties.

Vacuum tubes are now employed for electric wave detection, radio frequency and audio frequency amplification, radio telephony, particularly in the airplane radiophone, continuous wave radio telegraphy, voltage and current regulators on generators, and for other miscellaneous purposes. However, varied as are the applications at present, the uses, actual and potential, growing out of war development work have proved that the art of Vaccum Tube Engineering, and the application of its products to radio engineering, telephone and telegraph engineering, and particularly to electrical engineering in general, are still in their early infancy. That vacuum tubes in various forms and sizes will, within a few years, become widely used in every field of electrical development and application is not to be denied.

The engineering advancement accomplished in less than two years represents at least a decade under the normal conditions of peace, and our profession will, it is hoped, profit by this particular salvage of war which offers perhaps the most striking example extant of a minimum "time-lag" between the advanced "firing line" of so-called pure physics, and applied engineering.

The Chief Signal Officer considers that the work of standardization and quantity production of vacuum tubes accomplished during the last eighteen months under the pressure of military necessity, represents an advance in the art of electrical engineering which will prove of inestimable industrial and scientific value to this country, and to the engineering world at large.

PLATE X.
A. I. E. E.
VOL. XXXVIII, NO. 2



[SQUIER]

MARTIN BOMBING PLANE—TWO LIBERTY ENGINES

AIRPLANE RADIO TELEPHONE SET

Prior to April, 1917, a few experiments had been made, in which speech had been transmitted from airplane to ground by radio methods; but the apparatus involved was hopelessly crude. On May 22, 1917, the Chief Signal Officer called a conference in his office at which the project of evolving a "voice command" equipment for airplanes, which should meet all the severe requirements of the military service, and which should be thoroughly standardized for quantity production, was definitely set in motion against time. The plan for accomplishing this was the same as in the evolution of the Liberty engine, and from the beginning this project was regarded as one of the major creative efforts in the development of the American Air Service. The present airplane radiophone, therefore, is the result of a period of intensive development work began shortly after we entered the war. The services of the Western Electric engineers were enlisted, and under the direction of the Signal Corps, rapid development resulted in successful tests as early as August, 1917. Speech was exchanged between airplanes twenty-five miles apart in October, and sample sets were sent at once to the Army in France for trial. Several thousands sets were ordered and have been completed and distributed to flying fields here and to the Air Service in France.

The satisfactory performance of this apparatus has resulted in a new type of military unit known as a voice-commanded squadron. The commander of an air fleet directs the movements of the individual units in any manner desired; the effectiveness of the squadron as a military machine is thereby enormously increased.

Other uses are in communicating information from airplanes to ground stations, and in directing one or more airplanes from a ground station. Innumerable applications will be evolved as the possibilities are realized.

The essential elements of the Airplane Radiophone are the power equipment, the radio equipment, and the antenna.

a. The power equipment includes a double-voltage direct-current generator driven by an air fan, with a vacuum-tube voltage regulator.

b. The radio equipment consists of the vacuum tube transmitting and receiving set, and the special telephone transmitters and receivers. Those of you who have heard the terrific roar of a Liberty engine will realize the difficulty of talking in an airplane in flight. The development of a transmitter which is affected by the human voice, and not by the enormously greater engine and wind noises, is one of the principal features of this set. Similarly, to shield the ears of the aviator from the same noises required a special combination of sound-insulating materials surrounding the telephone receivers and suitable for use within an aviator's helmet.

c. The antenna originally consisted of a flexible copper wire several hundred feet long, unreeled by the aviator and trailing almost horizontally behind the airplane. Modified antenna using much shorter wires fixed to the framework are now used.

The operation of the sets is extremely simple, all adjustments being made before leaving the ground. The only manipulation required of the aviator is that of the change-over switch to change from talking to listening.

AIRPLANE RADIO TELEGRAPH SET

The principal use of radio communication made during the war was in sending radio telegraph signals from observation airplaines, for controlling artillery fire. The French developed a set which consisted of several units, making the installation and operation complicated. The Signal Corps developed a self-contained set, which has been demonstrated to be far superior to any other airplane set.

It consists of three units—first, the 200-watt, 900-cycle alternator, driven by a regulating air fan, and containing in a stream line case attached to the generator, all the elements of the radio set. This radio apparatus is of the synchronous spark type, with four spark tones and nine wave lengths. The weight of the complete unit is only twenty three pounds, and size only six inches by six inches by twenty-six inches. The regulating air fan maintains the speed of the generator within four per cent of 4500 rev. per min., with air velocities between 60 and 200 miles an hour.

The remaining units in the complete set are a variometer or tuning coil, with antenna ammeter attached, and the antenna system, comprising a reel, insulated bushing, and training antenna. When it is realized that voltages of thirty thousand or more are produced by this set, the difficulties of insulation in such restricted spaces will be appreciated.

Ranges of communication of one hundred miles have been accomplished with this set.

AIRPLANE DIRECTION FINDER

One of the principal problems of airplane navigation has been the evolution of a suitable compass, particularly for night bombing work. Magnetic and gyroscopic compasses have limitations at present which make impossible reliable air navigation by dead reckoning.

The use of directional effects of loops or coils for receiving radio signals have resulted in the development of a radio compass for airplanes which gives positive information to the aerial navigator, and enables him either to locate his position by triangulation with respect to two beacon land stations, or to fly at any given angle with respect to a certain beacon station.

The apparatus consists of two principal parts—the antenna coils, and the tuning and amplifying apparatus. The antenna coils are mounted in the fuselage of the Handley-Page airplane, with suitable means for rotating in azimuth. The amplifier is extremely sensitive, consisting of a detector and six-stage amplifier. A novel feature of the amplifier is the use of iron-core transformers for frequencies of 100,000 cycles.

The direction of the beacon land radio station is determined by maximum strength of signals, in a highly ingenious manner developed originally by the British. The precission of the directional effect is remarkable. In fact the radio direction finder may well be called a radio eye, by which the aerial navigator sees one or more radio lighthouses which are sending identifying signals to guide him on this way. These lighthouses, furthermore, have certain advantages over the normal light-house in that their ranges may be much greater, and they are not invisible in the day time nor obscured by fog and mist.

The remarkable advances made during the last eighteen months have resulted in the application of radio communication to practically every phase of military aviation. Commercial and military possibilities have, however, hardly been touched as yet. It is believed that radio apparatus soon will be as essential on aircraft as it now is on ocean going steamships, and that its use will enormously increase the effectiveness of aircraft for all purposes.

XII—The Liberty Aircraft Engine

FOREWORD

AS we look back on the record of accomplishment in the problem of obtaining large numbers of high powered aviation engines for our Army and Navy Air Services both in this country and abroad, it seems to those of us who were in close contact with the work and the difficulties more like a fairy tale than the statement of hard facts which it is in reality. On the face of things, it certainly would seem to be the height of presumption to assume that this country could, following its almost total neglect of aviation development in previous years, hope to design, develop and produce in unprecedented quantities an acceptable aircraft engine of greater power than had yet been evolved by any of the European nations, even under their spurs of governmental encouragement and tremendous war demands. Yet just that and nothing else was the only thing to do, and the story of its doing is one of the most brilliant chapters in the history of our Country's part in the Great War.

INITIAL SITUATION

At the time this country entered the war, in April 1917, there were being built in the United States only four makes of engines that were developed so far as to be considered of any military value, and even these were useful only for primary training. We had no engines at all suitable for services on the battle front, or even for the advanced training of pilots. The largest engine of domestic manufacture developed about 220 horse power and had not proved satisfactory when judged from the standpoint of combat service requirements. The others ranged in power from 90 h. p. to 135 h. p. It, therefore, was evident that the existing American engines could be used for preliminary instruction purposes only, and that their further manufacture should be limited to the training requirements. This was done, with the result that by far the greater portion of the primary training of pilots has been conducted with the Curtis OX-5 90-h. p. engine, the quantity production of which was early obtained. This engine was particularly valuable, owing to the very satisfactory training plane which had been designed around it. The Hall-Scott A7-A 100-h. p. engine was also extensively used at first until the production of the Curtiss engine could be brought to a point to meet all demands for primary training.

Two European engines, the Gnome 100-h. p. and the Hispano-Suiza 150-h. p., were being put into production in this country early in 1917, by the General Vehicle Company and the Wright-Martin Aircraft Corporation respectively. These concerns had obtained contracts with Great Britain and France, but were experiencing considerable difficulty in getting production under way. The production of the first Gnome engine was not completed until a period of more than nine months had elapsed, during all of which time English experts were present in the contractor's plant and aiding the manufacture. In the case of the Hispano-Suiza, notwithstanding the assistance of a group of French experts sent over to help get it into production in the minimum time, thirteen months were required to get the first production engine on the test block, and another month before the first delivery was made. Preparation periods were filled with the most costly experiments and the development of methods and tools for performing the intricate operations required by the design of these engines. All of which expense and delay had cost our Allies dearly.

The Gnome and Hispano-Suiza engines represented the highest product of European design and were in a perfected and standardized state, according to foreign practise and conditions, when their production was undertaken in this country. Nevertheless, the changes involved in adapting them to manufacture by American methods, and the development of expert workers for those operations which could not readily be so adapted, required so much time that the advances made in aeronautical engineering rendered such engines largely obsolete for service at the front, by the time they could be produced in sufficient numbers to supply any material portion of the requirements.

These two engines were, however, of unquestioned value for advanced training purposes, the Hispano-Suiza in particular being a dominant factor in this work. Later the Le Rhone 80-h. p. was put into production by the Union Switch & Signal Company and, by proper utilization of the lessons learned in the case of the other two foreign engines, reasonably satisfactory progress was made in manufacture. This engine, too, was used for advanced training work.

LIBERTY ENGINE INCEPTION AND EXPERIMENTAL DEVELOPMENT

One of the serious mistakes which the Allies had fallen into at the time the United States entered the war was the development of a multiplicity of types of engines and planes which made it impossible to have a large number of any one of these types. As a further consequence, the trained personnel on the ground to operate and repair the machines had grown to such a proportion that it was estimated that from thirty to fifty men were required on the ground to keep each one of the many types of planes in the air on the fighting line. Manifestly, unless this large number of trained men per fighting plane could be reduced by some means it would be hopeless to expect within a reasonable time to put into the air thousands of flying planes, because a single thousand planes on this basis would require from 30,000 to 50,000 men in attendance.

The experience obtained in getting two foreign engines into production in this country and under our manufacturing methods, so thoroughly demonstrated the futility of attempting any such solution of our service engine problem as to at once eliminate its continued consideration. It was realized that copies of foreign designs could not be available in time and in adequate size or numbers to answer the demand for an overwhelming air force at the front. American air performance would have been very small indeed if limited by such a handicap as this.

Moreover, in spite of the fact that a technical commission was at once organized and despatched for the purpose of getting first hand information on the front and in the aircraft centers of Europe, it was unthinkable that this country should sit idly by and wait perhaps months for the final definite report which should decide the nature and extent of our part in the Allied aircraft program. Since the most successful airplanes are designed around specific engines, and the engine involves the greatest expenditure of time and effort in development, it was apparent to a few of us who were in close contact with the situation that it would in all likelihood be possible to design, develop and produce an entirely new American engine, embodying characteristics which would render it particularly adapted to manufacture under American conditions, in less time than would be required by the commission to determine the particular European engines that offered the best approximation to the various exacting requirements of service and production, plus the time to get it in production in this country. It was decided, therefore, that our efforts should be directed along both these channels simultaneously and in addition to purchase in Europe whatever service equipment might be available, to tide over the interval while we were getting into production.

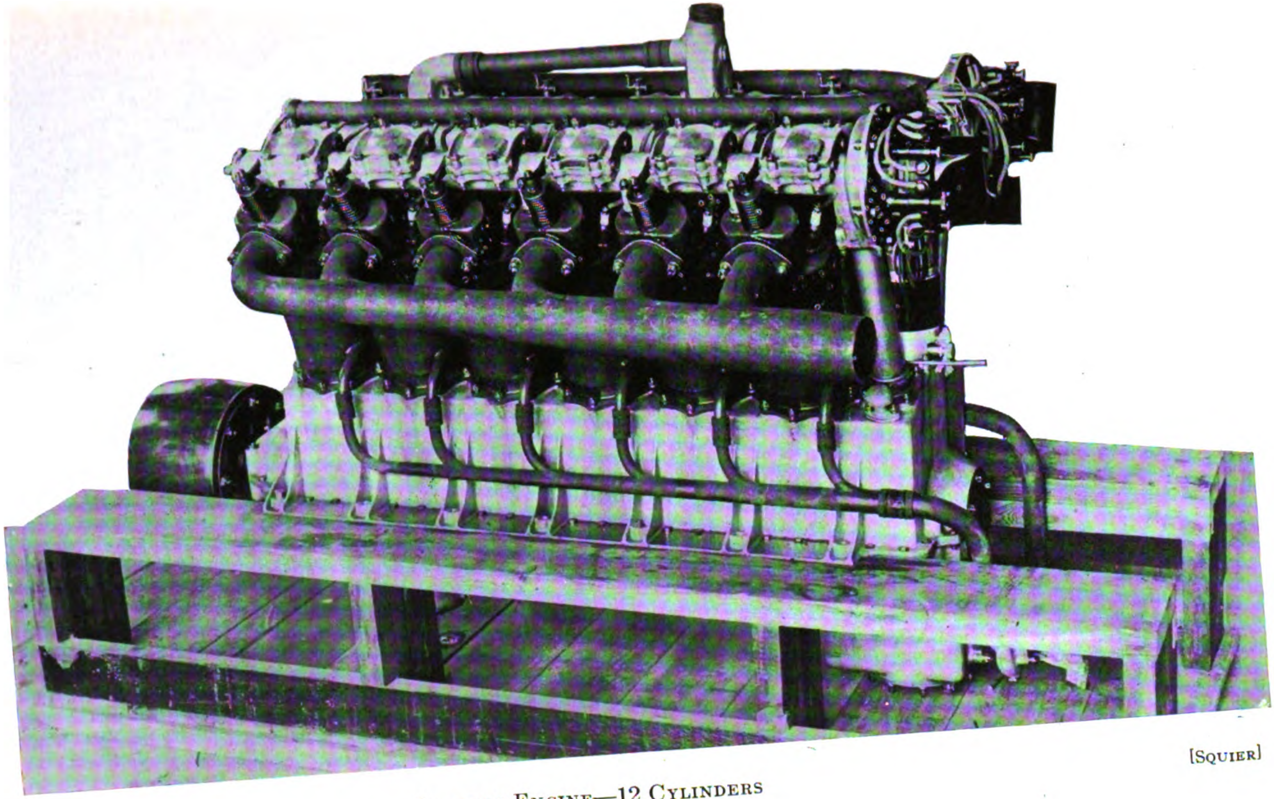
It is apparent that the fundamental unit of engine design or construction is the cylinder, and that the evolution of engine power rested mainly with the unit power capacity of that cylinder which could be taken as representing the largest practicable size sanctioned by the state of the art at that time. Starting with the foundation of this cylinder then, it was the most direct reasoning to conclude that all requirements of the service for engines of varying power capacities could be most logically met by combining these unit cylinders into groups of whatever number were required to produce the several sizes of engines desired. This was done, and the cylinder size of five inches bore by seven inches stroke was selected, after a careful examination of the performance of both American and European engines of the then most modern design, as being the largest that could be relied upon to give satisfactory service. While originally designed to produce approximately 28 h. p., this cylinder has been so developed as to yield at present more than 40 h. p. as the result of somewhat increasing the speed and altering the functioning characteristics. The standard unit cylinders were to be used in engines having four or more cylinders each and yielding the following power output:

Number of Cylinders.	Original Rated h.p.
4	110
6	165
8	225
12	335

Thus, for the first time in the history of the aeronautic engine for military uses, a truly comprehensive design plan was evolved which in a simple and direct manner provided for the production of a whole line of engines of wide power capacities, but composed of units that were highly standardized and therefore could be really manufactured, instead of being merely built. This was, and is, the only way in which this country could meet the requirements of this most vital part of the program.

It must not be thought, however, that such a revolutionary decision was easy to make, or adhere to when made, in the face of all kinds of adverse criticism, some of which seemed to be based upon adequate grounds. The development of new types of aircraft engines heretofore had been such a time-consuming matter that it was generally regarded as a thing to be avoided if any ready-developed engine could be found anywhere which would at all answer the requirements. Thus the numerical preponderance of opinion was against the possibility of a standardized American engine being designed, developed, and produced in large numbers, in anything like as short a time as would be required to duplicate some European engine. The nation may well render thanks that its destinies in this particular were guided by such a far-seeing and courageous group of men, who had the ability to formulate such plans and then to enforce their realization.

You are all familiar to some extent with the history of the design and construction of this engine:—how Lieutenant Colonels J. G. Vincent, of the Packard Co., and E. J. Hall, of the Hall-Scott Motor Car Co., laid down the general features and got out the first assembly drawings personally between mid-day of May 29 and the afternoon of May 31, 1917, working in Col. E. A. Deed's apartment in a Washington hotel in response to a request for a report on the aircraft engine situation, which came from Howard E. Coffin, Chairman of the Aircraft Production Board; the Chief Signal Officer of the Army; Colonel Edward A. Deeds, Chief of the Equipment Division, Signal Corps, and Colonel Sidney D. Waldon, Assistant Chief:—how the order to build ten sample eights and twelves was given as the result of the approval by the joint conference of the Army and Navy Technical Board and the Aircraft Production Board:—how the first engine, an eight-cylinder, was built in one month as a result of the enthusiastic cooperation of some ten manufacturers, each of whom produced those parts for which they were best fitted:—how the first sample twelve-cylinder finished its official fifty-hour endurance test eighty-two days from the time the order for samples was given, and that the total elapsed time during this test was only about fifty five hours, a record-breaking performance:—and how the success of this endurance test definitely removed the engine from the experimental stage to the realm of proved engines.



[SQUIER]

LIBERTY ENGINE—12 CYLINDERS

A very gratifying endorsement of this standardized engine project came from the late Colonel R. C. Bolling, whose untimely death in France cost the American Air Service one of its most valuable officers, and Col. V. E. Clark, and Lieut. Col. Howard C. Marmon, members of the commission sent abroad to ascertain the requirements, and which returned about this time, to the effect that a 400 h. p. engine was absolutely demanded at the front for the types of airplanes which it had been decided this country should supply, and that no engine of this size then existed in Europe.

Those of us who are familiar with the difficulties and disappointments involved in the design, development and perfection of any form of intricate mechanical device can readily appreciate the really remarkable accomplishment represented in the Liberty. Therefore, it is not at all surprising that the representatives of the Allies were for some time unable to believe the full truth of this accomplishment. They never had been able to obtain such action and were, naturally, only fully convinced after many varied and exhaustive tests. So well recognized did the value of the Liberty engine become, however, that the Allies had on order at the time of signing the armistice 16,741 Liberty engines, and were constantly endeavoring each to increase their rate of monthly delivery. Airplanes were being designed around this engine in all Allied countries and it was fast becoming the predominating aeronautical engine of the Allied cause.

It is of interest in this connection to note that this standardized engine already has been tested in the twenty-four cylinder model, and shown results which prove that the original basic idea will provide for engines of any size which would have been required for any probable increase in airplane size during years of continuation of the war. The sixteen cylinder was also proved by the success of the larger engine.

The experimental development of the Liberty has been in charge of a department entirely separate from that dealing with its production, the Airplane Engineering Department under Lieut. Col. J. C. Vincent and Lieut. Col. Howard C. Marmon. The work of this department has resulted in a continuous improvement of the power output and performance characteristics of the Liberty twelve cylinder, to such an extent that 526 h. p. have been obtained with special fuel and detail changes; certainly a remarkable increase from the

335 h. p. which the original design was intended to yield. While the weight of the service engine per horse power has remained at approximately two pounds, the maximum present development had reduced this figure to one and two thirds pounds.

LIBERTY PRODUCTION—DEVELOPMENT AND PRODUCTION

The record of production and production-development of the Liberty conclusively proves the wisdom of the decision to concentrate all efforts on this one engine for the major part of our program of combat engines. In common with all similar machines, many possible improvements and cost reductions become evident as the manufacturing processes and tools are being evolved and as experience is being acquired in the actual production. Also, experience in the operating and adjustment of these engines led to alterations being made which resulted in increasing the power output; so that when we were advised that more power was desired than the 335 h. p. which the original Liberty was designed to produce, the necessary steps already were known and the delay incidental to putting them into effect was small. The resulting power increase to about 375 h. p. answered requirements for several months when advices were again received that more power was needed, and we then again made such alterations as were required to increase the power to around 420 h. p. The weight of some of the parts was increased at this time in order that the reliability might not be reduced.

The problem of production was placed in the hands of a separate department in charge of Lieut. H. H. Emmons, U.S.N., and the continuous assistance of such men as Henry M. Leland, of the Lincoln Motors Co.; C. Harold Wills, of the Ford Motor Co.; F. F. Beall, O. E. Hunt and Edward Roberts, all of the Packard Motor Co., were obtained by Major J. G. Heaslet, in charge of the Detroit district. The work of Mr. Wills which has the greatest value was the perfection of a new process for the forging of cylinder blanks in sufficient quantities to supply all manufacturers, and which was so very effective that the problem of cylinder forging supply and cost was reduced to a minor consideration. The wisdom of the action taken is evidenced by the production of 1100 Liberty 12s in one year from the day when Messrs. Vincent and Hall first met and started a preliminary drawing, and over 15,000 by the end of another six months.

It is perhaps to be expected that many criticisms would be leveled at an engine evolved under the conditions obtaining at that time, and registering the large success which it represents, but all such have proved to be the result of misinformation regarding the conditions to be met, the fundamental ideas of design, or of lack of appreciation of the difficulties encountered in creating at a single stroke and without previous experience, an aeronautical power plant so much larger than was then in existence.

The Liberty engine stands today as an achievement which for daring, constructive imagination and farsightedness will ever be a cause of pride to the American people.

XIII—A Granular Theory of Armies

IN these days we are face to face with the so-called granular theory of electricity and matter, whose fundamental unit is the electron. From one angle of view, as I shall hope to show, there is also a granular theory of armies.

The history of the military operations of the past disclose the fact that the actual combatant troops are specially selected men most fit physically for the hardships of war. In general terms the actual fighting has been restricted to selected persons from the male population with definite maximum and minimum limits for age and also definite requirements for the vital physical functions.

In the language of the physicist we may say that the male population of a nation is carefully segregated by a sort of "band filter" which picks out for combatant warfare only those whose age cycles fall between say eighteen and thirty years. These selected men are then brought to a further common standard by intensive physical training before they are permitted actual combatant service. This elevation of the military unit to a common physical standard makes possible, as will be readily seen, the formation of larger units such as companies, battalions, brigades, divisions, corps and armies and their direction by a centralized command in the tactics of war.

Invoking the law of averages, we may say furthermore that,—*the one unchanging factor in warfare is the individual physical strength of a man.*

The soldiers of Ceasar's army were physically no stronger nor weaker than our own. On the average, a battalion or company of soldiers from one nation can march, for instance, just as far in a day as a battalion or company from any other nation, and this statement was equally true before the Christian era, and is not likely to change in the future.

In consequence of this fact, military supremacy must be looked for primarily in the weapons and agencies provided by scientists and engineers and placed in the hands of these combatant units to multiply their military strength.

To illustrate, the day in the fourteenth century, when Berthold Schwartz or whoever actually invented gunpowder, put together charcoal, sulphur and saltpeter, he, by a scientific act, and at a single stroke, exerted more influence upon the development of warfare and indeed the history of the world since that time, than many armies could accomplish by any mere physical qualities which they possessed.

Stated in another way, if our enemies in the recent great conflict had been made up wholly of civilizations like those of Turkey and Bulgaria, nearly all of the agencies which I have been describing during the past hour would have been utterly impossible of either development or production by them. There were no Liberty engines nor airplane radio sets evolved or made in this quarter, nor could there be such without outside aid.

It follows from this, that those civilizations which by their scientific and engineering training can create and manufacture these agencies, will and must control the fortunes of war in the future, or far better, apply these same agencies, in a potential way, to banish war from the world for all time.

The present war has made aviation in four years what it would have taken two decades at least to accomplish in times of peace, and has multiplied the reach and capabilities of the physical military unit to an extent which is only now in the beginning. May we not fervently hope that the further development of aerial navigation will place in our hands such potential destructive powers as to go a long way toward making war impossible again?

I can say no more at the present time.

* * * * * *

IN conclusion, the courteous invitation of the Board of Directors of this Institute to address you on this occasion, suggested that I may have some message to deliver to the American Engineer.

The organization of the American Air Service requiring, *inter alia*, the foundation of a new industry under the adverse conditions above outlined, involved a creative project worthy of the broad conceptions for which the United States is noted.

When the United States entered the war, it was evident that the time was fast approaching when the reservoirs of raw material for the allies were to be found only in the United States and that America's effort should be so organized from the beginning as to furnish a continuous flow of this necessary raw material, not only for our own air program but for those of our Allies as well. It was clear, for instance, that the spruce, the fabric, the dope and the oil must be produced as a part of our program on a scale to supply also the air programs of our Allies. It was always the general Allied cause therefore which controlled the decisions in founding this industry, rather than the needs of the United States alone, and this is obviously the only correct point of view.

It is believed that the major decisions which had to be made by those in authority were accurately made, and promptly executed, and that as a consequence the record of the United States Air Service during the war shows a creditable performance. If America will but press on into the future, building upon the sound foundations now erected, she may lead the world in the development and utilization of aerial navigation for the triumphs of peace.

By a wise policy of readjustment, utilizing immediately our machines and our surplus aviators for the rapid expansion of the aerial mail and special passenger services, it will be possible to salvage for the nation a greater percentage of the money and energy invested for strictly war purposes than from any other feature of our war activities.

As a steward of the people, and in all humility therefore, I must not shrink from answering, as best I may, your request for a message which applies equally to peace and war.

The general principles which governed in the making of this enterprise in all of its ramifications of material and personnel, and to which the success attained must be attributed, may perhaps be formulated as follows:

VICTORY CREED

To foster individual talent, imagination and initiative, to couple with this a high degree of cooperation, and to subject these to a not too minute direction; the whole vitalized by a supreme purpose which serves as the magic key to unlock the upper strata of the energies of men.

Presented at the 342d Meeting of the American Institute of Electrical Engineers, Philadelphia, Pa., December 13, 1918.

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(*Subject to final revision for the Transactions.*)

AMERICAN ENGINEERING RESEARCH

BY W. R. WHITNEY

THE purpose of this paper is to call attention to our national condition in relation to engineering research, in the hope that the desire among engineers to advance the sciences may be discussed and crystallized into the most acceptable form. The subject must have some sharpness of definition, and so I will give the meanings I attach to the title.

I am using the word research, to cover painstaking investigations which *add* to knowledge. Research alone may be too general a term to interest all engineers, so I limit my use of the term by the adjective "engineering", and mean by that, the study of matter. Much research may be done in fields not connected with engineering, but I am not referring now to archaeological, geographical, psychological research, or other similar fields where study and experiment also add to human knowledge. For the sake of a simple and clear field I am omitting such sciences. I use the prefix American, to call attention to one of the most burning questions which confronts us today. We have been so keen in engineering that American engineering is unsurpassed in the world, but we never made a fair start in American engineering research. Moreover, we have no plan for producing research men, though we have plenty of plans for consuming them.

Research is the foundation of engineering, whether it be electrical, physical, chemical, biological, or what not. It sometimes seems as though much of our best engineering is only very slightly removed from the original research in time or space. If the research forms the foundation, then engineers quickly add the first story. When the investigators showed the value of typhus vaccination, the Army doctors used it on a million soldiers. General Gorgas recently wrote Dr. Keen that of over 1½ million soldiers, there were only 18 deaths from this disease in 1917. At the Civil War rate there would have been 7200 deaths. That is good American engineering research. But who is responsible for the research men? How may we procure and support them? A part of this responsibility is your own.

During a certain period of our American history there was a Puritan atmosphere in research. It hung like a fog over the territory of the Pilgrims, and even now it clouds the issues between engineering and research. It meant purity to the extent of sterility. It was with interest that I recently read, with the above geographical thought in mind, one of Emerson's Essays. He puts our duty in such a clear light that, before going into problems of detail, I want to quote him. His use of exactly the right word to give clearness to his thought seems very wonderful and his words will bear a more careful analysis than anything I can say.

> The destiny of organized nature is amelioration and who can tell its limits? It is for man to tame the chaos. On every side while he lives, to scatter the seeds of science and of song, that climate, corn, animals and men may be milder and the germs of love and benefit may be multiplied.

If we could all learn that by heart, I could well stop my talk at this point.

The experience of the past few months developed in the mind of practically every intelligent man a desire to do something to advance the country's interest. This was not confined to scientists and engineers, but was marked in those cases. The number of scientific and engineering organizations which evinced this desirable spirit is too long to read. Our leading societies united in committees representing all the sciences, and they in turn formed many sub-committees. The National Research Council enlisted in one committee or another almost all the scientists of the country. The Council of National Defense established scores of committees on engineering and allied lines. Inventories of everything conceivable were taken, including most of the material and personnel of our colleges and engineering schools.

Now there is one defect in this system of rapid utilization of our resources. It does not produce any new material, though it may organize the old. We needed organized engineering research long before the war. We needed it more during the war, and we shall certainly need it after the war. It is the duty of engineers to study this matter and take active steps to correct it. The problem is: how shall we insure the preparation of plenty of American men of science by some system which makes us independent of foreign assistance? My belief is that it can well be done in our existing colleges by greater attention to new material truth. Experimental work in the sciences best prepares and preserves those desirable qualities in teachers: interest and enthusiasm. Any plan which would insure properly supported investigators whose vocation was experiment and whose avocation was teaching, where students could *work* with them, would be a most natural development. It is a way already thoroughly tested abroad and would be a step of the greatest value to this country.

It is unfortunate that we have no generally acceptable plan for insuring our scientific work and our engineering research. There has been little better than chaos on this subject thus far in America: No one's life work was research, though to a few it was a by-product. Within the past few years, and in a few lines in certain universities, investigations into the laws or properties of matter have been under way. This has been poorly appreciated. The *exceptions* are those successes which led to rapid physical amelioration, as of death or pain (naturally the first places for such appreciation). The value of research on the hook worm is readily understood. Heredity-studies in corn or cattle are recognized as worth while, but there are many researches undertaken whose value is not so apparent on the surface, and yet whose ultimate potency is warrant for their consummation. But for us at present, while the product of research work is desirable, the preparation of the men is of greater importance.

Because our condition has been described before and remedies suggested, is no reason why attention should not be called to it again. Something should be done. Important steps in a democracy call for repeated attempts to inform the interested people. Perhaps scores of addresses on general preparedness delivered before the war were wasted, but it was safer to assume that the reiteration was necessary.

It is owing to our Yankee inventiveness that I am interested in seeing much greater attention given to the problems of our engineering research. We are inclined to be so elated by our apparent successes in industry, that we imagine that there is some way to build without foundation, to practise without experience, to reap where we have never sown. Hundreds of thousands of inventors are choking our patent offices with ideas which can have but one end, the unhappy end of the inventor. This condition is wrong. We cannot wish to perpetuate it. It may be greatly ameliorated by careful planning of engineering and research education in America. This planning falls as a duty on the engineers themselves.

There is a general opinion that discovery of truth is very prevalent here, and that somewhere in our national archives there lie buried a lot of wonderful but undeveloped possibilities. You have probably received notices from different groups of people who want to bring to light and life some such desirable inventions. As a matter of fact, there are probably very few such things in existence. One reason is that there is actually more capital to develop new ideas and more capitalists who see possibilities which do not exist, than are justified by works. In fact, while we lack training and knowledge as inventors, we more sorely lack men who are sufficiently expert to pass with certainty on suggestions of abnormal minds. The reason the steam engine and the submarine were not earlier recognized was due to the scarcity of men who knew science. When we had one Langley on aeronautics we needed 100. Paucity of knowledge is our present trouble, not superabundance of inventions. The point in this illustration is that we badly need more highly trained quantitative men of science. Our National planning for research, except for research in agriculture (which planning, strange to say, was done during the Civil War), has been entirely neglected. Agriculture is not our only interest, but even in that field, the future lies in the hands of the young research chemists and engineers who should do the work on potash and fixed nitrogen.

It is on this point of the special need for planning that I want to lay stress. Ways to accomplish the end have been tested and proved. Particularly during the past century there have appeared in other countries men who devoted their entire time to study in fields of new knowledge which by contact had attracted them. We might possibly have called them specialists, high brows, hobbyists, or men of large interrogation. They were very valuable.

These men were found in many walks of life, but by far the greater part of them were, or soon became, attached to foreign universities. They gave fully of their products to one another and took extreme and careful steps to give to the world accurate and detailed reports of their researches. Davy and Faraday were of this type, Liebig and Wöhler were like them, and it is safe to say that such benefactors of the race could be cited by the hundred. In most cases their entire lives were spent in their laboratories and all that they learned was freely published. Still more important; in the laboratories of these men, particularly promising students were allowed to work, and these teachers illustrated for them scientific research by example. They did not confine their teaching to talks about the work of others. The men referred to, and others, such as Helmholtz, Kelvin, Berthelot, and more recent prototypes, such as Ramsay, Moissan, and Haber, were alike in these respects. We have produced altogether too few of them in America, and supported none. They became unusual men, but they started much like others. They were developed by a system or plan. As they developed in interest, in knowledge of new things, and grew abnormal in this respect, the opportunity for further development was provided, usually by the state. There is no reason to assume that the product they represent cannot be grown on American soil. They were the result of a policy almost identical in all cases. Each was freed by some planned system to evolve himself and follow his studies along the lines he chose, and he was given the assistance of students who were at the same time learning the value and rare power of careful thought and painstaking investigation. They created atmospheres of scientific pioneering. The teacher was the leader. He was exploring. His interest was transferred to others by that most direct way—close contact. The lines of scientific endeavor were not chosen by some remote director, or committee of experiment, but the subject itself led the investigator along, and new truth was the sole aim. The professor then became the leader in the university, because he was following a new line of action and not because, at the request of a faculty committee, he was perhaps trying to solve some particular indigenous problem, or reducing the cost of some existing factory product. He was being led by Nature, instead of trying, as the industrial laboratories so often do, to force Nature along lines which we think most desirable.

Someone has suggested that possibly our industrial research laboratories could supply the country's deficiency in scientific research and its teaching. Many industrial laboratories have been established recently, but, to my mind, there does not seem the slightest possibility of thus meeting the real need of the country. It is neither natural, nor desirable, and most recent writers on the subject have been clear on this point. The interesting papers by Colonel Carty, Dr. Jewett, and Mr.

Skinner, in the TRANSACTIONS of the A. I. E. E., are in good accord on this point.

It may be asked, do you consider it a good plan to arrange our colleges so that every teacher with a hobby may develop it by the aid of the students? If all our teachers had enjoyed good training in science and were good scientific investigators, the answer would certainly be "yes", but this is not always the case. Therefore we must lend our aid in helping to establish a condition which will insure a greater number of scientific teachers who are also trained as productive scientists. This is in reality the method employed in those countries where scientific education has been most advanced.

In other words, our great American engineering problem today is not, how shall we make use of our trained investigators? Shall we organize a few large centers of research and solve there the industrial problems of the country, or, shall we encourage and assist the industries to give more attention to research work? But it is rather: how may we produce annually active young students of matter at a greater rate but of higher quality than any other country? We must think in terms of thousands per year of the type of trained men represented, say by the doctor's degree, or by two or more years of individual experimental work.

The direct object of this paper is not to ask for the appointment of some committee to cooperate in planning American engineering training and knowledge. We do not need more committees for this work, but more constructive activity on a dozen existing committees. In other words, enough machinery already exists to do the work, and we need but a clear view of the necessary steps. Probably no one person has completed a perfect plan, but many have advanced suggestions, all of which seem to have failed to meet sufficient acceptance to move the wheels. My own ideas are not presented as new and original. They are plans of others, but they seem most natural and desirable because they accept higher education as our common right. They seem democratic.

Several years ago the American Association for the Advancement of Science appointed a Committee of One Hundred to bring about cooperation between universities and industries along the line of improving our work in science, its growth, and its use. Other organizations undertook similar studies, but at that time most of the effort was expended in arranging for the use of, rather than for the production of facts, or of useful men. It was a shortsighted plan, helpful but not broad enough. In several colleges, research fellowships have been established, but these were generally for the solution of definite manufacturing problems where private interests seemed justified in paying for the work. This was done because scientific research which was aimed solely towards new physical truth could not be thus supported. Such methods are doubtless useful, but their aim is low. They advance single industries but are not intended to establish and make known new truths. Such organizations will only rarely become research centers where new leads in science will be persistently followed by groups of intensely interested investigators. There is greater value and attraction in disclosure of new physical phenomena than in any probable financial returns, and the atmosphere in a laboratory of scientific research is a thing by itself. But it cannot evolve of itself, and it is for practical beneficiaries, such as engineers and the public, to find the way.

Central bureaus of science and research have been repeatedly advocated and many are still being planned. The plans vary from separate departmental government laboratories like those of the Department of Agriculture, the Bureau of Mines, and the Bureau of Standards, to those of separate groups of colleges, groups of industries, societies, and finally, groups of men. One such is the most recent plan of the National Institute of Inventors. None of these is probably perfect. Most of them would consume (possibly ossify), but not produce men. Perhaps all of them should be studied by engineers and some of them developed, but if many were carried out, it would immediately become evident that our crying need is for general college research work to prepare trained investigators.

A few years ago a bill was prepared for Congress which had for its object the establishment of engineering research work in the federally assisted colleges of the country, and this called for additional federal support. One of the criticisms of the plan was that it did not include all colleges. It had been thought that the precedent having been established in 1862 of giving governmental aid to these institutions for their research and teaching work in agriculture, it might not be difficult to extend this line of activity to other scientific research work. One of the reasons this bill was not sufficiently supported was that a large number of struggling state universities and other colleges objected to the distinction which would be made. This finally led to other proposals being drafted, and one, known as the Smith-Howard Bill, seems to be the most satisfactory suggestion yet made. Others are also appearing. It is not my intention to go into the details of this bill here. But its existence and its fundamental concept deserves your careful attention and your active interest. It called for funds for research in the colleges; $15,000. for a college in each state. Fifteen minutes of our present year's war cost would care for that plan a whole year. The plan seems a good experiment, but needs support. This line of thought raises the question whether our democracy should pay for its education and its standing in science and engineering, or whether it should be left to accidental philanthropy, to the begging ability of college presidents, or be neglected altogether.

President Shurman, of Cornell, said a few months ago:

> Germany has the advantage over all her opponents, especially Great Britain and the United States, in the solid fabric she has constructed during the last generation by means of generous government encouragement of, and appreciation for, scientific research and instruction. Our Government today, instructed by the war, is ready to spend billions of dollars for new scientific truths in which, prior to the war, it felt no concern and for which it would make no provisions.

This same thought has been expressed by others in many ways. The facts are pretty well known, but are still not entirely digested. We are such creatures of habit that we may never awaken to the fact that we are a slow but sanguine people. Slow, because our rate of advance as measured over the last century is less than Japan's; sanguine, because we hope for the best without being willing to provide for it.

If you consult the university president or engineering educator who is well acquainted with higher education in America and ask him why we have been so backward in the highest class of scientific teaching, he will generally reply, "lack of money". We are forced to train so many men to reach a certain stage of preparedness for standard vocations that we cannot afford to encourage advanced work nor can we obtain teachers who are primarily workers in their science. Our conditions in America are still in that stage of teaching where our energies must be exclusively used to repeat to students annually certain knowledge already acquired, but we cannot provide for acquirement of new knowledge nor for the training of men to obtain it. As far as our collective powers and plans go, the sciences would remain stationary.

Apparently persons of highest intelligence believe that while our schools should be supported by taxation, this should apply only up to a certain grade. Above that grade we should beg private interests for our advance in knowledge and for our most highly trained men, for our studies of disease and our search for cures. This fact accounts for the difficulty of the college president. It is merely a bad habit. Certainly no one really approves of it. Everyone who thinks carefully can find plenty of fault with it, but the engineering of a better plan is left undone. That is an engineer's job. In the past few decades intelligent men of wealth have fortunately recognized some of the needs of higher education in our country where our pioneer activities have not developed any satisfactory system. By this means, great good has certainly been accomplished, but the philanthropic method can scarcely be a strengthening one. It cannot lead to proper appreciation of the value of the advancement of knowledge by the people.

One of our greatest dangers is that, knowing how Germany arranged her higher education, quickly advanced and reaped those returns which were so harmful to us, we may spurn the adoption of some similar scheme because of the degraded utility she finally made of it.

What do we want? We want our democracy to do as well in science as German autocracy did, until we learn to do better. I do not care to compare the scientific work of different countries, but I want to call attention to the peculiar way science was treated in Germany for the half century preceding the war. I want to show that some of her ablest men were life-long workers in and teachers of science; that they were leaders in their civil groups, that they were appreciated by the country and given the widest support and honor. We have too little to compare with it, and we collectively, or our Government, are not making sufficient effort to support new scientific work.

Let me once more warn you against the fear that material truth and experimental knowledge are a menace. Only indolent people think this, but it is frequently expressed. Professor Richards, of Harvard, says on this point (1916):

> Science has recently been blamed by superficial critics, but she is not at fault if her great potentialities are distorted to serve malignant ends. Is not this calamity (war) due rather to the fact that the spiritual enlightenment of humanity has not kept pace with the progress of science? The study of nature can lead an upright and humane civilization even higher

and higher to greater health and comfort and a sounder philosophy, but that same study can teach the ruthless and selfish how to destroy more efficiently than to create.

There are many European cities which owe their reputations to their scientific work. Most of them are university towns. Their renown is not based on the nine, nor on the eleven, nor on the local glee club. Freiburg, Bonn, Heidelberg, Jena, Charlottenburg, Leipzig, Halle, Karlsruhe, Gottingen, are such places. They recall scientific accomplishments. Some of our corresponding towns are Columbus, Ithaca, New Haven, Urbana, Madison, Princeton, Lawrence, Pittsburg, Burlington, Ames, and Lincoln. Does each remind you of scientific work? We are not yet doing our duty by them. Can we not help the scientific work in such towns?

Good scientists grow in all countries, but the support which investigators received in Germany is a point I want to emphasize. To the average physicist, chemist, or biologist, most of the following teachers recall fundamental advances in the sciences. I refer to men like Pettenkeffer, Liebig, Wöhler, Voit, Ludwig, Kühne, Hoppe-Seyler, Weber, Helmholtz, du Bois Reymond, Fechner, Engelmann, Pfluger, Hertwig, Leuckart, Ehrlich, Virchow, Hering, Emil Fisher, Buchner, Pfeffer, Weissman, Koch, Quincke, Hofmeister, Pringsheim, Boveri, Richter, Kekulé, Wislicenus, Kolbe, Hofman, Bunsen, Victor, Lothar and J. R. Meyer, Bayer, Clausius, Ostwald, Kolrausch, Planck, Nernst, Hertz, Boltzmann, Roentgen, Wien, and Haber.

Are we to suppose that America could not do as well? In my opinion, we should try the method already tested, and modify it from time to time as we see indicative developments.

The German universities operate under charters granted by the Government, which supports them. The faculty practically manages the institution, though the Government is represented by the curator, who manages the finances. The full professors regulate the internal affairs by their votes, and they elect their various officers, the rector, deans, etc.

On the other hand, we in America ask certain unprepared civilians to serve as our college trustees. They soon find that the condition of finances calls for help, and, together with the president, they must solve the almost insoluble problem of the year's budget. There is little chance for new work.- Practically every college has all it can possibly do to meet the demands of large classes of undergraduate students, and the trustees, despite their sympathy with scientific developments, cannot possibly care for demands which are less dominant. We have about 500 universities or colleges in this country. Many of them are equipped with everything necessary for good scientific work except the encouragement. Many laboratories are better equipped than those abroad. Would it not be worth while to arrange for the modest addition to our educational expenses which a fair trial of American university research would entail?

The Students' Army Training Corps has recently thrown all our colleges into an unsatisfactory and an unstable condition. Had that work continued, it is possible that permanent improvements in education would have resulted. It was too radical to continue, and the pressing need has disappeared, but we have all seen the possibilities of quickly effecting such changes, and we ought now to work and hope for some justifiable improvements. Is it good engineering to force the presumed leaders of our highest education to spend their best energies in perpetual scrambles for funds, instead of directing education? Probably no one thinks so, but everyone waits for the change to be forced by someone else.

The recent report on Engineering Education, published through the Carnegie Foundation, to which we are greatly indebted, leaves me with the thought that the past aim of our engineering education was to teach carefully selected men to merely repeat certain standard processes and thereby earn a livelihood. This is not enough. Watch good, experienced engineers at work and see them plan. Is their work repetition of old steps they were taught? It is nearer right to say that they were always trying experiments. We read daily of the newest and largest building, the most novel or the longest bridge, new types of tunnels or subways, longer range guns and new armor plates, lighter aero engines, larger turbines, heavier locomotives, Armco iron, Tantiron, Duriron, Monel, Stellite, etc., etc. There is certainly no limit to this line. Therefore I would not teach fixity, but right change, and do it by precept and *example.* I would increase for the engineer, during his college years, the facility with which he could begin to learn the elasticity and nobility of his calling, and that by contact with men interested in experiment.

What will be done to continue more men in advanced scientific lines in college? Can you engineers not help here? Is it not a good plan to arrange for the highest possible training on the part of a selected few? Is it not the duty of organized engineers and scientists to take part in activities which influence legislation and to make our country the foremost for new finds in nature and in the development of men? Engineers will then be co-products with investigators.

I would be better satisfied with this suggestion if I did not know that very few realize how much the strength of a whole people depends on its scientific novelties. The facts are frequently something like this: some searcher for new truth in natural phenomena uncovers a fact. He gets a few dollars or a little mental satisfaction out of it. A few industries then base the work and the living of many people upon it, and its value, there, may be expressed in, say, many thousands of dollars. But it is not so readily seen that the people at large get most of the return and are therefore most highly interested in the advance. Their earnings in such cases are in millions and their advantages incalculable. The telegraph and telephone, the gas engine, the aeroplane, wireless, artificial lights, and all engineering improvements have this in common. The ratios may be 1 to 1000 to 1,000,000 for the three groups, but the largest group does least planning. It is not organized for it. Engineering societies might do this.

Large central laboratories of research recently suggested for industrial chemistry are worth good trial, and are being tried in England, but to be most effective they would have to follow somewhat the lines of other smaller laboratories. We have knowledge in such cases which may be of value. Several now exist in which scores of experimenters are employed. A group of one hundred working on miscellaneous research would probably represent between one-half and one million dollars a year outlay. The return would be problematical and cannot be estimated, but would seem very promising in various lines of federal interest. One result is, however, certain. Manned at once with any hundred investigators now available, it would be very much less useful than if manned with well trained research men, of whom we have too few. Our already extensive use of trained men such as electricians, chemists, and physicists is exceeding the supply.

That the young men of our colleges and engineering schools early quit school and went into war work is not a cause for complaint. That in itself was a splendid thing and accomplished wonders. Over a thousand young chemists have done the work of our gas mask development, our poisonous gases, our smoke screens, our new explosives, etc., and the physicists went into the wireless, the submarine defense work, and similar problems in large numbers and with marked success. They have done things which older men would not have undertaken. Therefore this is rather a complaint that we had so few young engineers, and is a petition that in the future the supply be insured and the energies directed to peace time needs.

I do not see any possible way of insuring our future commercial and engineering supremacy that can compare with utilizing our colleges more perfectly. When barbarous war methods are forever stopped, science and engineering should be the main factors recognized by the League of Nations as the legitimate ground for a nation's supremacy. How can we better insure our position than by taking care of that amelioration which tames the chaos for all the people?

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RESEARCH IN AMERICA AFTER THE WAR

BY R. A. MILLIKAN

IT takes no statement from the chairman nor admission from myself, to apprise most of you of the fact that I belong to the genus "Damn professor," as we are affectionately called in Washington.

It may interest you, however, and perhaps be a little diverting too, to know how nearly we professors have to come to acting like real soldiers once in a while when we get on suitable clothes. About four weeks ago I chanced to go from Waterbury, Conn., to New Haven, on a trolley, starting about half past eleven o'clock at night. At a small station between the two towns, there boarded the trolley a couple of well-filled soldiers. They took seats on opposite sides of the car and began quarreling loudly. The conductor was quite unable to cope with the situation; finally the men arose and began hammering each other back and forth across the car. The passengers were in an uproar, when someone called "Here's an officer, let him attend to it." So with the aid of a couple of privates, I had to take part in getting these men into their seats, a task which we succeeded in accomplishing, thanks to the respect inspired by my uniform, and a certain muscular efficiency which the privates showed. We later succeeded in getting the drunks off the train.

Another incident, which has elements almost as heroic, occurred one night last summer when I was on the way from Washington to New York. I stopped off in Baltimore, for no ulterior or interior reasons, although it might have looked as if I had such motives from the fact that I missed the train at Baltimore and had to sit down in the station and wait for another train. In order to utilize my time, I took out my brief case and began writing. In doing so, I pulled my fountain pen from my pocket, and the cap fell off on the floor. Before I had time to recover it, an elderly lady, about sixty years old, rushed from her seat and brought it back to me saying, "Oh, let me do something for a soldier."

To experiences like these should be added the sweet delight which a soldier hero feels as he passes through Indiana and Illinois (as I did yesterday) of not only being permitted, but of actually being forced to take from fair young hands reached up to the windows of the train, sandwiches made of thin slices of bread and thick slices of chicken, with a dill pickle added, all free to the man in uniform.

But the tragedies and the comedies of the war are ended. To use the memorable words of the official announcement of the British War Office—words so brief, so modest, so tactful that they contrast strangely with the vulgar boastings of both our press and our statesmen. "In the fifty-second month of a war without precedent in history, the French Army, aided by the Allies, has achieved the defeat of the enemy," And with the ending of the war all of our war activities either have ceased already or will soon do so.

But there are things that the war has done which should not, which fortunately will not, cease. Men like Dr. Whitney and like myself have been pulled out of the ruts in which our lives had been running and have been thrown into completely new surroundings; men from England have come to this country to teach our young soldiers, and to participate in our war researches; millions of our own men have gone to France and Italy, and to England, so that, if ever there was a time in the history of the world, when men were in a position to begin to see things as the other fellow sees them, to get a little larger outlook than they normally have, that time is surely the present. The country is just now in a state of fluidity, and before the crystallization process has set in great things may be accomplished. Movements which the inertia of mankind make it normally impossible to bring to fruition in any reasonable time, can now be put across with relative ease; for we are all seeing how things look from some other angle than that from which we have been in the habit of looking at them. So that the next few months, so it seems to me, are going to be pregnant months for the history of the United States and of the world.

I wish, then, to call attention to a few of the lessons which from my point of view, the war has taught, and I trust I shall be able to do something more than to make a mere academic recital of them, for I hope that I may bring something before you which will inspire to action.

In the research activities in the aid of the war in which I have been associated, one thing has stood out exceedingly strikingly; namely, that the distinctions between the man whom you commonly call the pure scientist and the man whom you call the applied scientist have absolutely disappeared. In every one of the eighty or ninety researches with which I have had connection there have been associated physicists from the colleges, engineers from the General Electric Company, the Westinghouse Electric and Manufacturing Company, the Western Electric Company, and other companies, and they have all worked as one, and you could no more make one of these men say, "This problem belongs to physicists," or, "This belongs to engineers," than you could say that a man's head belongs to one being and his body to another. The pure and applied scientists have functioned as one single group as they have never done before, and I hope very much that we may be able to do something right now to keep bridged the chasm between the academic group and the industrial group. This chasm is unquestionably a detriment to both groups and an effective bar to progress—a bar which Germany had removed in some fields, at least, much better than we have. If the process of forming societies has already gone so far in this country that for the purposes of organization and classification—which are to be looked upon always as necessary evils—the Physical Society and the Engineering Societies must continue to exist as distinct units, at any rate I certainly feel that it is possible to bring about such an interlocking of committees within these societies that the two organizations may act in many respects as one, and I hope that this possibility will soon become a reality.

You noticed in Dr. Whitney's address that engineering research was defined as "anything which had to do with matter." That is fairly broad, isn't it, and it wipes out completely all of these distinctions about which I have been speaking. I am quite willing to accept his definition, and I would not object to being called an engineer if that is what it means to be one. As a matter of fact, I presume I should have had more satisfaction in my war work if I could have been called an engineer instead of a "damn scientist." You certainly cannot draw any distinction between scientists and engineers on the basis of the utilities of their work, and you all know that you cannot.

I know of hardly an investigation in so-called pure science which has not sooner or later found its utility, nor do I know of any so-called pure scientist whose motives are not utilitarian, in the sense that he believes that he is doing something which will sooner or later contribute to human good. But what I am aiming at is after all not mere words. A change of name alone is of no importance. What I want is rather an actual fusion of groups of men who are now further apart than they ought to be.

My second lesson is one of even greater importance. If there is anything which has been demonstrated by the experiences not only of America, but of all other countries in this war, it is that one cannot safely depend upon the so-called undirected inventive genius of a people to obtain large results. Advances have been made in this war almost exclusively by one method, namely that of bringing together groups of well trained thoroughly competent men and setting them upon the problems needing solution. In other words large and rapid progress has been made in this war and in my judgment it can in general be made only by adopting the strictly research method of approach. In this war every one of the major belligerent countries has had its Board of Inventions, and it has been the uniform experience in all of them, in Italy, France, England, and the United States, that not one suggestion in ten thousand which is of any value comes in through these bodies. Further, the chance is about 100 to 1 that the good suggestion which does occasionally come in this way has already been thought of, and worked upon, by the groups of trained men who have been giving their attention and skill exclusively to these research matters.

But how much in the past have we used this method? How much have we done in this country during the last hundred years in organizing such research groups? Dr. Remsen told me the other day that in 1872, when he was first called to Johns Hopkins, there was not a place in the United States where there was any research atmosphere or where any serious research work was being done. Perhaps some one may wish to raise a question as to the literal accuracy of that statement, but on the whole it gives a correct picture of the research development and the research interest in this country at the time of which Dr. Remsen spoke. I would not cast any dimness over the luster of names like those of Franklin and Henry and men of that type whom this country had produced before that time, but, after all, these were individual geniuses. They were not the leaders of research groups and yet they accomplished wonderful things. But we have passed from the stage of the world's development in which we could depend solely on individual geniuses for advancing the wheels of progress. If these wheels are to move forward rapidly we must do in peace exactly as we have done in this war, namely, call together groups of research men in our industries, in our educational institutions—I do not care where—give them the problems, and let them push them forward. In this way these wheels will move forward ten times as rapidly, yes, a hundred times as rapidly, as will be the case if we depend upon the exceptional inventive genius of the country, however valuable that may have been to us in the past.

These are the two lessons which I would draw from the war.

Let me next ask you to consider how we may profit by them, and perhaps the path which we ought to take may be made more clear if we analyze ourselves somewhat objectively, and try to look, for the time being at least, not at our virtues but at our weaknesses, however disagreeable such introspection may be. Let me begin by asserting that in spite of our boasted inventiveness, we are as yet, from the scientific standpoint, a second rate people, whether we look at our accomplishments in war or in peace. I am certainly well within the bounds of the truth when I say that the contributions of the United States to this war in research and development lines have been less, far less, than is proportionate to our resources and our population. I think Dr. Whitney will agree that that is not an overstatement, and he knows fairly well what we have been doing, for he has been associated with much of it. England and France have both done far, far more effective war research than we have done. True, they have had more time, but they have not had either the men or the facilities which we have had. With almost every available man in France at the front, with most of her manufacturing facilities in the hands of the enemy, is it not an extraordinary tribute to the French scientific mind that the two most novel and most promising weapons which we had at the close of the war for combating the submarine came out of France. We have done some creditable work in this country on submarine detection, but in comparison with the number of men engaged on the work and the facilities at command, both France and England did vastly more than we. The other day an officer who had

had exceptional opportunity to appraise our contribution to the war was in my office and I was bewailing the fact that a particular device which we had been developing had not been completed in time to be of actual use on the front. But said I—"I do not know that I ought to complain, because I presume that it is in the same boat with approximately 96 per cent of all American effort." Said he—"I think you overestimate the amount that got across."

Now that is an impression which one does not gain from the newspapers. I would not unduly belittle the American effort, but I would like to do something to combat the lethal poison which is being introduced into the American system by the vain-glorious boasting in which our newspapers and politicians are indulging. We did indeed cast the deciding vote. It is true that save for us the Kaiser might not perhaps have been so easily persuaded to call out "Don't shoot Boss, I'll come down," but let us at least remember that 20 Frenchmen gave up their lives for every American boy who died, that more than ten Englishmen "died for France" to one American. These figures show the real pressure of our contribution, and let us not forget them.

Again I state that whether one measures our position by our contributions to the war, or, what is more to the point to-night, by our accomplishments in science in times of peace, I think that every American who is perfectly honest with himself will admit that we have no claim as yet to being anything more than a second rate people. Second rate whether you take as the criterion of first rate-ness either the number of men of outstanding ability and reputation which we possess, or the total output of the country in proportion to our population, or the general appreciation and respect in which science is held in the community at large. Look at the first criterion; who would for a moment claim that we can show a list of names comparable with these? Faraday, Maxwell, Kelvin, Stokes, Rayleigh, Thomson, Larmor, Schuster, Rutherford, Jeans. Or going to the field of chemistry, in which we have done as well perhaps as in any science, who would undertake to present such a list of illustrious American names as that which Dr. Whitney has just presented for Germany?

When we look at the second criterion and reflect that we have 100,000,000 population against England's 45,000,000 and Holland's 4,000,000, no man who is at all familiar with our relative outputs would claim for a moment our equality with either of them. It will be generally admitted that as measured by this criterion we cannot think of claiming to be in the first rank. Such a statement may not be palatable to our pride, but it is true in spite of the fact that you see so much in our newspapers and elsewhere which might lead you to think otherwise. Here is something fairly typical. There is a tablet erected in Dayton, Ohio, which gives a list of twenty of the world's greatest inventions, and attributes thirteen of them to the United States, just one to England, the locomotive, one to Scotland, the steam engine, two to Germany, the Fahrenheit thermometer and the X-Ray, only one to France, the daguerreotype, but two to Italy, the pendulum clock and wireless, and two to Dayton, the cash register and the airplane. Such claims need no comment. Unfortunately they are more or less typical. I wish they were not typical, and perhaps we may do something to make them less so.

As for the third criterion, the public appreciation of science in any country may be gaged first by the general respect and honor in which the calling of the scientist is held, and second by the character of the general scientific journals which that country supports. Now it is a matter of common knowledge that in all European countries the scientist is held in greater respect than in this country, and as for journals, let me just mention the names of three English publications in different fields and see what kind of comparisons they bring up in your minds. The *Philosophical Magazine, The London Electrician and Nature.* Have we journals which are of a full equality with any of these?

I am presenting these unpleasant truths not because I think our situation is hopeless, but just exactly because I think these conditions are remediable, and because I think that you and I can assist in changing them. I say them because I believe in all my heart in the effectiveness in the long run of our American democracy. I say them because I believe with all my heart that when you once get the public opinion of the United States aroused it will set about changing bad conditions and will do it rapidly. You and I have already seen it doing certain things which a few years ago nobody believed a democracy could do. We have seen it handling the liquor problem for example in a better way, as it seems to me, than that in which it is being handled in any country in the world, and this is the last problem which you would expect that a democracy could handle. I am pointing out conditions which ought not to exist because I believe at the bottom of my heart that our method, the democratic method, is capable of rectifying bad conditions more rapidly on the whole than is any other method, if only we can once get the real situation and the real need before the consciousness of the American people.

What we need then if we would become a first-rate rather than a second-rate people from the standpoint of our scientific development is, first, the development of more highly trained and more able scientific personnel in this country than we now have. Second, we need the development of a new public opinion on scientific matters. We need appreciation of what science is and what it can do. We do not need any more so-called "Popular Science Monthlys," but we do need a better educated, scientific intelligence than we have at the present time.

How are we going to get these things? Dr. Whitney has said that we have enough organizations. Maybe we have, at any rate we have not enough of concerted action among existing organizations. This is precisely what the National Research Council is endeavoring now to bring about, and if the Research Council cannot succeed in this work which it has been organized to do, then some other organization must arise which will do it. In other words, we must in some way get the scientific men of the country pulling together. I think this can be done and that it is the biggest, most worth while enterprise which any of us have ever had an opportunity to take part in. The problem is to persuade the engineering societies, and the physical societies, and the biological societies, and the medical fraternities, no longer to work all by themselves, but instead to pull all together in one common effort, first to educate the American public to a larger appreciation of the possibilities of science, second, to make the present American scientist more effective than he now is, and third and most important, to find means by which we may develop more and better scientific men.

The education of the public is of course a slow process, but it can be accomplished by directed effort and concerted action such as the Council is now attempting to bring about. The stimulation to greater effectiveness of existing scientific men also cannot fail to result from all of these new activities. But the producing of a continuous new crop of able scientific men is a problem to which I should like to give a little more detailed consideration. *The result aimed at can be attained only through the agency of the American Universities.* These however cannot possibly make the kind of men Dr. Whitney wants out of poor material. Something can be done to a man by education alone, and yet there is no one who knows as well as the college professor how little merely going through the routine of getting an education amounts to. Our primary need is to find a way of getting a better *selection* of men than we now have, that is, a way of diverting the brains that now exist in the country into research channels. How is that to be done? The answer is to my mind very direct though perhaps not so simple, since it involves funds. It is to deliberately and consciously set about the task of creating more opportunities for research careers than we now have, and giving greater dignity to such careers. In connection with American Universities, I see ways in which this can be done, first by persuading philanthropic men and institutions to endow a considerable number of scholarships similar to the so-called 1851 Exhibition Scholarship of the British Universities, second, by the creation through private means of many more partial research professorships than we now have. I say partial research professorships because I think that the research man needs the broadening influence of a small amount of advanced teaching even for the greatest effectiveness in his research work. The creation of more pure research institutes like the Rockefeller Institute for Medical Research or the various research laboratories of the Carnegie Institution of Washington, may also be encouraged though I am myself a strong believer in building up research enterprises in connection with educational institutions so that the atmosphere of research may be inhaled by the young blood which is continually passing through these institutions. Create a real research atmosphere in a score of American Universities and a new generation of research men will quickly be created which will place America in the front rank in the fields of science. I should regard it as a calamity if the research funds available in America went exclusively or even primarily into the founding of central research laboratories. This country already has scores of magnificently equipped laboratories which produce one tenth as much as European laboratories one fourth as well equipped. We do not want more brick and mortar, more physical facilities, *we want more and better men*. As Dr. Whitney has so well said, *we want a man-producing program, not merely a man-consuming program. The man-producing agencies are primarily the universities.*

Funds which are donated to colleges or universities for research work should be devoted by the terms of gift to research purposes and made altogether undivertable into the purely educational budget. One of the chief aims of the Research Council has been from the start to stimulate this sort of giving. The finest outgrowth of our democratic, individualistic civilization has been the development of a great multitude of public spirited men who devote their means to public ends and it will probably continue to be true in the future as it has in the past that our biggest and most important public enterprises will be inaugurated not by public but by private initiative. I see no reason therefore for not using the method which has been most successful in the past in many fields and which is most characteristic of the genius of Anglo-Saxon institutions —viz., the method of the private foundation of research scholarships and professorships.

But I agree with Dr Whitney that in a country like this, there is no reason why the federal government, as well as private persons and institutions, should not promote the development of research. The whole world has been aroused by the war to the importance of this sort of activity. England has appropriated governmental funds for scientific and industrial research, and Canada has done the same, and so has Australia, and Italy, and I think Japan also. The United States is almost the only large country which has not thus far done anything in this direction. But there is now before Congress a bill—the so-called Smith-Howard Bill—which in its original form had most unfortunate features, but which is apparently now in process of being changed into a really valuable measure. I am permitted to say that the authors and sponsors of this bill recently asked the National Research Council to appoint a committee to give it thorough study and make possible recommendations. A fairly representative committee of some ten men, including Dr. Whitney and the Director of the Bureau of Standards and the author of the bill, Mr. P. V. Stephens, has met and reported unanimously upon certain types of modifications in that bill. The most essential of these changes consist in the setting up of the principle, different from that incorporated in the original bill, that the funds appropriated by the federal government to each state shall be allotted to institutions within the state *by a board composed of at least five of the most eminent available scientists and engineers of the state, upon the basis of programs of research submitted annually by these institutions to this scientific board.* It was the judgment of the Committee, and also of the executive board of the National Research Council which unanimously approved this report, that if the allottment of research funds within each state can be placed in the hands of men who know what research is, and if the institutions of a state can be stimulated to a rivalry in the development of research programs there will develop in existing laboratories of which we have already an abundance, an atmosphere of research which is now wanting. *It is only through the creation of such atmospheres that research men can be developed.* This sort of a plan seems to make it possible to plant men all over the country who will be creating such atmospheres. It provides for the stimulation of research throughout the country in both industrial and pure science lines much better than any scheme for federal aid which I have seen discussed.

There is very grave danger, however, that the desire of public officials, legislators and private individuals to leave brick and mortar *monuments* to themselves will divert funds which ought to go to the development of men to the creation of more elaborately equipped laboratories without men, such as already constitute a reflection upon American judgment and American brains. If the Smith-Howard Bill modified in some such vital way as I have indicated does not pass then I have little doubt that the National Research Council will in time itself establish within the states research boards which may then obtain state funds to be used in some such way. California has already such a State Board, working in cooperation with the National Research Council and this board has within the past year received and appropriated more than $50,000 for research within California.

I have said enough to suggest many ways in which research in industrial and pure science lines is likely to be stimulated in the near future. Let me close with a brief word on the organization of the National Research Council which is occupying itself with these large problems of the promotion of research in the United States by a method which is compatible with the genius of our Anglo-Saxon institutions, namely, by the democratic method of the voluntary associations of research men, societies and institutions into a great body which can effectively create public sentiment and stimulate in a large way research enterprises.

The Council is, in a word, simply a federation of the research organizations and activities of the United States for the purpose of obtaining concerted action, mapping out new lines of progress, establishing the cross connections between different fields, acting as a central bureau of information and coordination, and promoting research in general. It has for the past year had a so-called war organization, because one of the most important problems which confronted our country was to get the scientific and engineering brains of the country effectively at work upon its war problems. The National Research Council has been one of the influential and effective agencies which has been doing this and it has thrown all its energies into the task. Now the time has come when it must reorganize so as to adapt itself as completely as possible to the problems of peace, which are more important even than those of war. The present tentative plan is to have the Council a thoroughly representative body in that at least a majority of its membership is essentially elected by the constitutent societies for a period of say three years. Each of the seven or eight divisions, namely, the division of Engineering, the division of Physics, Geophysics, Astronomy, Mathematics, the division of Chemistry and Chemical Technology, the division of Medicine and related sciences, the division of Biology, the division of Geology and related sciences, etc., to consist of 25 to 35 men presided over by a chairman elected by the group. The most essential feature of the proposed organization is the Executive Board which consists of these eight chairmen, eight vice-chairman and say ten members at large. The Board would meet at least once a month in Washington. The eight chairmen are to give up, in general, all other activities for their term of office, of probably a year's duration, to be paid suitable salaries, say $6,000 a year, are to be resident in Washington, and to devote their whole time while in office to the promotion of research in the United States. With eight of the best and most influential scientific men in the country devoting themselves each year to the large problems of surveying, stimulating, and coordinating the research activities of the country, the United States can I believe very soon be placed in the front of the nations of the earth in scientific discovery and its application to the arts and industries.

The National Research Council bespeaks your active cooperation and support in this great new democratic and characteristically American program.

To be presented at the 7th Midwinter Convention of the American Institute of Electrical Engineers, New York, February 21, 1919.

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THE DIELECTRIC STRENGTH OF AIR FILMS ENTRAPPED IN SOLID INSULATION AND A PRACTICAL APPLICATION OF THE PROBLEM FOR ALTERNATOR COILS AND CABLES

BY F. DUBSKY

ABSTRACT OF PAPER

It is of theoretical importance, as well as of practical importance in design, to be able to predetermine the dielectric strength of air films or bubbles entrapped in solid insulation.

If such films are over-stressed the solid insulation may be damaged by chemical action, local heating, mechanical action etc., due to corona.

An experimental investigation was made of the strength of air films of various thicknesses between glass plates. In the arrangement used, the breakdown of the air or the starting point of corona could be readily observed. Tests were also made of the dielectric strength of air films between other solid insulations.

It was found that the dielectric strength of air films between insulations was practically the same as the dielectric strength of air films between conductors.

The second part of the paper is devoted to the practical application of the data to the design of armature coils and cables, and several specific examples are given.

Part I

THE DIELECTRIC STRENGTH OF AIR FILMS

THIN air films or bubbles are often entrapped in the solid insulation used in coils, cables and other electrical apparatus. Air is weaker than solid insulations, and when placed in series with them in an electric field, as is usually the case for entrapped air, it takes a much greater unit stress. This follows because the same flux passes through the different dielectrics and the air has the lowest permittivity or offers the highest resistance to the flux.

It becomes of great practical importance to be able to predict the behavior of these films and the voltage at which their break-down occurs. The break-down of an air bubble or film usually will not cause immediate break-down of the solid insulation; it may result, however, in gradual deterioration for the following reasons:

1. Heating due to the losses in corona.
2. Chemical action due to the formation of ozone and nitric acid.
3. Mechanical action due to a rapid movement of the corona streamers.
4. The formation of conducting paths by chemical action and carbonization.

The dielectric strength of air in the form of very thin spacings or films *between conductors* has been studied by a number of investigators†; it has recently been treated very thoroughly by F. W. Peek, Jr. and the resulting laws and data are published in several papers and in his book‡.

It is the object of the present investigation to determine experimentally if the laws and data referred to apply when the air films are not between metallic conductors, but exist as pockets in the solid insulation. For this reason, in the tests which will be described later, the break down strength of air was measured on films between glass plates and between insulated conductors.

The data on air films between metal surfaces referred to above will first be discussed.

Air Films Between Metal Surfaces. The dielectric strength of air is the voltage gradient or the volts per unit distance which must be reached before the spark-over of an air space in a uniform electric field can occur. For the thin films, or small spacings under consideration here, the field may be considered as uniform.

The dielectric strength of air is proportional to the air density, which varies directly with the pressure and inversely as the absolute temperature. If the air density at a temperature of 25 deg. cent. and a barometric pressure of 76 cm. is taken as unity, the relative air density δ at other temperatures and pressures may be expressed in terms of it, thus:

$$\delta = \frac{3.92\, b}{273 + t} \qquad (1)$$

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†Harris J. Ryan, TRANS. A. I. E. E., 1911, Vol. XXX, Part I, page 8, Fig. 6, giving the Baille-Paschen-Schuster results.

‡F. W. Peek, Jr., TRANS. A. I. E. E., 1913, Vol. XXXII, Part II, pages 1335 to 1355, *Law of Corona and Dielectric Strength of Air.*

F. W. Peek, Jr., In his book "Dielectric Phenomena in High Voltage Engineering", Chap. III on Visual Corona, Chap. X on Design of Apparatus where Solid, Liquid and Gaseous Insulations enter in Combinations, where $b =$ barometric pressure in centimeters,

$t =$ temperature in degrees centigrade.

If $G_0 =$ dielectric strength of air in effective volts per mil in a uniform electric field at 25 deg. cent. and 76 cm. barometric pressure, and

$G =$ dielectric strength of air in effective volts per mil in a uniform electric field at temperature of t deg. cent. and barometric pressure of b cm.

$$G = G_0 \delta \tag{2}$$

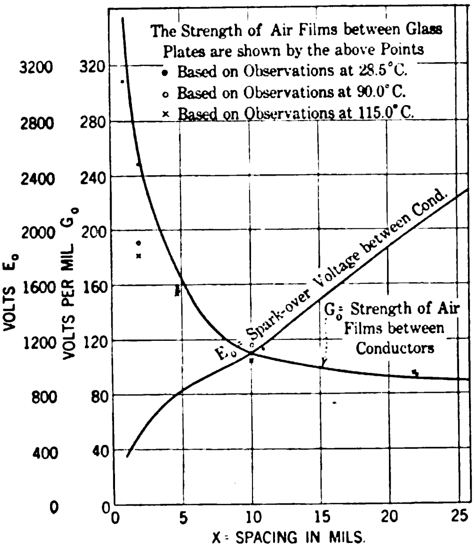

FIG. 1A—DIELECTRIC STRENGTH AND SPARK-OVER VOLTAGE OF AIR FILMS AT $t = 25$ DEG. CENT. AND $b = 76$ CM.

Further, if $X =$ air space in mils, since the field is uniform,

$$E_0 = X G_0 \tag{3}$$

$$E = X G \tag{4}$$

where E_0 and E are respectively the effective sine-wave spark-over voltages of the air space.

In Figs. 1A and 1B are plotted two curves showing the strength G_0 and the spark-over voltage E_0 for different thicknesses of air films between metal surfaces at 25 deg. cent. and 76 cm. barometer. This data was obtained from the investigation referred to above*; the spacing is expressed in terms of mils to be more conveniently applied.

It would be expected that this strength of air would hold also whenever thin air spacings occur in combination with layers of various solid insulations. In order to apply this data, however, it is first necessary to calculate the stress or gradient on the entrapped air. That this may be simply done is shown below.

Calculation of the Stress or Gradient in Air Films in Solid Insulation. Taking a general case when n dielectrics of thicknesses $X_1, X_2 \ldots X_i \ldots X_n$ mils and of relative permittivities $k_1, k_2 \ldots k_i \ldots k_n$ respectively, are arranged in a uniform electric field in series so that the same dielectric flux density passes through each material, the expression for the gradient in any dielectric of the combination of the n insulations is

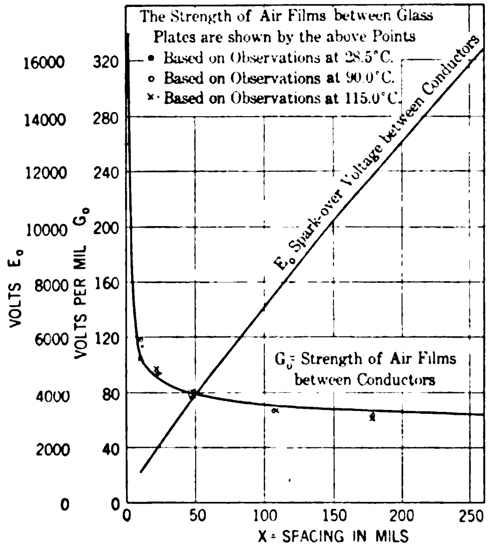

FIG. 1B—DIELECTRIC STRENGTH AND SPARK-OVER VOLTAGE OF AIR AIR FILMS AT $t = 25$ DEG. CENT. AND $b = 76$ CM.

$$g_i = \frac{E}{k_i\left(\frac{X_1}{k_1} + \frac{X_2}{k_2} + \ldots + \frac{X_i}{k_i} + \ldots + \frac{X_n}{k_n}\right)} \quad (5)$$

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*F. W. Peek, Jr., TRANS. A. I. E. E., Vol. XXX, Part II, 1913, p. 1348.

where E = voltage across the terminals in volts.
If X_1, g_1 and k_1 are respectively the thickness, gradient and permittivity of the air film,
and hence $k_1 = 1$, it follows that

$$g_i = \frac{E}{k_i\left(X_1 + \frac{X_2}{k_2} + \ldots + \frac{X_i}{k_i} + \ldots + \frac{X_n}{k_n}\right)} \quad (6)$$

and

$$g_1 = \frac{E}{\left(X_1 + \frac{X_2}{k_2} + \ldots + \frac{X_i}{k_i} + \ldots + \frac{X_n}{k_n}\right)} \quad (7)$$

The latter equation is used to determine the dielectric stress in air whenever the air enters into combination with solid insulation. The stress on the relatively weak air will always be much greater than the stress on the solid insulation. When the dielectric stress reaches the critical value, the air film breaks down with the appearance of visual corona, characterized by a pale violet glow, a hissing noise and the odor of ozone.

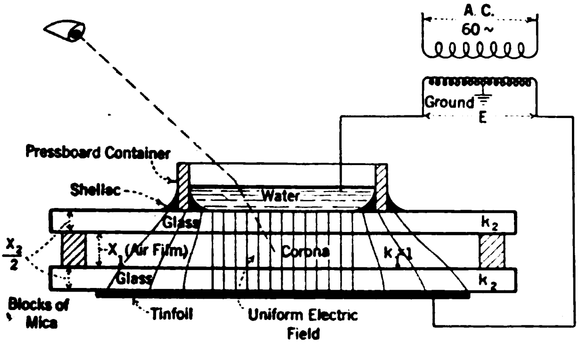

FIG. 2—CORONA TESTS ON AIR FILMS BETWEEN TWO GLASS PLATES

Description of Tests to Determine the Strength of Air Films between Solid Insulations. The corona tests were made with varying air space between two pieces of white French plate glass each 8 in. by 15 in. (see Fig. 2). Small blocks of mica were used to secure the desired space between the glass plates. The tests were made at practically sine-wave voltage, at a frequency of 60 cycles per second.

The lower terminal was a piece of tinfoil 6 in. by 12 in. pressed into intimate contact with the glass. The upper terminal consisted of water held in place by a container of pressboard fastened to the glass with shellac. Water was used as the upper electrode so that the start of corona could be readily observed through the water and the glass plate. The air film did not make contact with either electrode, but did with the glass plates.

The tests were made first at room temperature and then at higher temperatures by the use of an oven. In the latter case the same arrangement was used with the exception of the top terminal, to which calcium chloride was added in order to raise the boiling point of the water.

The voltage was very gradually increased and the start of corona was observed in a dark room by looking through the water terminal and the upper glass plate. The break-down point, as indicated by the pale violet glow in the air film, could be very accurately determined.

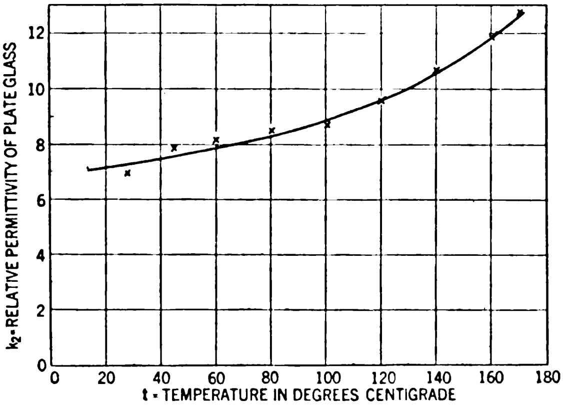

Fig. 3—Variation of Permittivity of Plate Glass with Temperature

This interesting experiment was suggested by Mr. F. W. Peek, Jr.

The observed data and the values calculated therefrom are given in Table I where the following designations are used:

X_1 = air space in mils,
X_2 = average thickness of both glass plates,
E = effective sine wave volts between terminals,
b = barometric pressure in cm.,
t = average temperature in deg. cent. of glass plates and air space,

k_2 = relative permittivity of the plate glass. In Fig. 3 is plotted a curve giving the relation between the relative permittivity of the plate glass (used in the above tests) and the temperature from 25 to 170 deg. cent. The data for this curve were obtained from capacitance measurements, on one of the 8 in. by 15 in. glass plates. A sheet of tinfoil 6.625 in. by 13.625 in. was pasted on each side of the glass plate with dry shellac and smoothed out with a hot iron. The maximum, minimum and average values of thickness in 20 measurements were 0.194 in., 0.160 in. and 0.176 in. Capacity measurements were made with a Hoxie capaciometer.

$g_2 = \dfrac{E}{k_2\left(X_1 + \dfrac{X_2}{k_2}\right)}$ = gradient in the glass at the start of corona, expressed in effective volts per mil at observed temperature and barometric pressure.

$g_1 = \dfrac{E}{X_1 + \dfrac{X_2}{k_2}}$ = critical gradient in the air between the glass plates at the start of corona, expressed in effective volts per mil at observed temperature and barometric pressure.

$\delta = \dfrac{3.92\,b}{273 + t}$ = relative air density at observed temperature t in deg. cent. and barometric pressure b in cm.

$g'_{1,0} = g_1\,\delta$ = critical gradient in air between glass plates at start of corona, expressed in effective volts per mil reduced to 25 deg. cent. temperature and 76 cm. barometric pressure = the dielectric strength of air between glass plates, expressed in effective volts per mil at 25 deg. cent. temperature and 76 cm. barometric pressure.

In the last column of Table I is given

G_0 = dielectric strength of air *between conductors* in effective volts per mil at 25 deg. cent. temperature and 76 cm. barometric pressure,

which values were taken for comparison from Figs. 1A and 1B for the air spacings X_1 referred to in Table I.

Finally it should be stated that the values $g_{1,0}$ obtained in Table I are plotted in Figs. 1A and 1B along the curve giving G_0. The three symbols represent points based on three different temperatures of observation, (all reduced to t = 25 deg. cent. and b = 76 cm.).

The points, (especially those based on observations at 28.5 deg. cent.), practically coincide with the curves if the relative accuracy due to small spacings between glass plates is taken in consideration.

The results from corona tests on air space between two insulated conductors are given in the lower part of Table I in which case X_2 designates the both sides thickness of the conductor insulation built up of tapings.

TABLE I

CORONA TESTS ON AIR FILMS BETWEEN TWO GLASS PLATES

X_1	E	b	t	X_2	k_2	$\frac{X_2}{k_2}$	$X_1 + \frac{X_2}{k_2}$	g_2	g_1	δ	$g_{1,0}$	G_0
1	14,900	73.6	28.5	357	7.2	49.6	50.6	41	294	.96	307	353
2.1	12,300	"	"	"	"	"	51.7	33	238	"	247	250
4.8	8,200	"	"	"	"	"	54.4	21	151	"	157	170
11.0	6,600	"	"	"	"	"	60.6	15.1	109	"	113	106
22.2	6,400	"	"	"	"	"	71.8	12.4	89	"	93	90
48.0	7,600	"	"	"	"	"	97.6	10.8	78	"	81	79
108	10,100	"	"	"	"	"	157.6	8.9	64	"	67	70
179	13,500	"	"	"	"	"	228.6	8.2	59	"	61.5	66
2.0	6,500	72.3	90	357	8.5	42	44.0	17.4	148	.78	190	256
4.8	5,750	71.5	86	"	8.4	42.5	47.3	14.5	122	.78	156	170
10.2	4,810	71.5	87	"	8.4	42.5	52.7	10.9	91	.78	117	107
22.0	4,750	71.5	89	"	8.5	42	64.0	8.7	74	.775	95	91
47.3	5,625	72.2	88	"	8.45	42.3	89.6	7.4	63	.785	80	79.5
107	7,750	72.5	89.5	"	8.5	42	149	6.1	52	.785	66	70.5
179	11,000	72.5	88	"	8.45	42.3	221.3	5.9	50	.785	64	66
2.0	5,370	72.9	114	357	9.3	38.4	40.4	14.3	133	.738	181	256
4.8	4,940	"	114	"	9.3	38.4	43.2	12.3	115	.738	155	170
10.2	3,630	"	120	"	9.5	37.6	47.8	8.0	76	.728	105	107
22	4,125	72.5	116	354	9.4	37.7	59.7	7.3	69	.730	95	91
47.3	4,680	"	117	"	9.4	37.7	85.0	5.9	55	.728	76	79.5
108	7,125	"	114	"	9.3	38.1	146.1	5.3	49	.733	67	70
179	10,000	"	115	"	9.3	38.1	217.1	5.0	46	.732	63	66
Corona Tests on Air Films between Insulated Conductors.												
250	19,000	72.8	25	254	3.2	79	329	18.1	58	.95	61	63
250	15,800	72.8	107	254	3.5	73	323	13.9	48.7	.75	65	63

Conclusions from above Corona Tests. A comparison of the dielectric strength of *air films between conductors,* and *air films entrapped in solid insulation* shows as good agreement as could be expected; in a uniform electric field the phenomenon of start of corona in thin air films between layers of solid insulation apparently follows the same law as between conductors. It is important to show how practically to apply this data. This is done in Part II.

Part II

EFFECT OF AIR FILMS, AIR BUBBLES OR POCKETS, ENTRAPPED IN SOLID INSULATION UPON THE DESIGN OF ARMATURE COILS OF AIR-COOLED HIGH-VOLTAGE ALTERNATING-CURRENT MACHINES AND UPON THE DESIGN OF CABLES.

General Description of Coil Arrangement and Insulation in Alternators, Motors and Induction Regulators. The armature winding of air-cooled high-voltage alternating-current machines is usually of the barrel type. Three-phase windings are preferably connected in Y with grounded or ungrounded neutral. The form-wound coils are embedded in open slots; there are two coil-sections per slot.

There may be one or more turns per coil as shown in Fig. 4. Occasionally, when the number of turns per coil is large, the coil is wound with several layers and with several turns per layer.

The turns are often wound with several copper strands in multiple. Single-cotton covering, compound treatment, or both are used to insulate the strands so as to eliminate eddy current loss between strands.

The first coil of each phase, being connected to the line terminal, has full line potential to ground (volts between lines $/\sqrt{3}$); the potential of other coils to ground is less and decreases down to zero at the common neutral.

The potential difference between two coils and between top and botton leg of coils depends upon the location of the coils under consideration, and varies between a maximum value equal to the voltage between two line terminals and a minimum value equal to the induced voltage of two coils.

Usually all coils are wound and insulated alike. The insulation of each coil to ground must be designed for the line potential to ground, E, and the total insulation from copper to copper between two coils must stand a potential difference $\sqrt{3}\,E$.

Since there are two thicknesses of insulation between coils, it is possible to reduce the thickness of the coil insulation in the end portion of coils to about 87 per cent of the thickness of the coil insulation in the slot portion. The mechanical reenforcement rings supporting the end portion of the winding must then be sufficiently insulated and spaced from the insulated coils so as to give from copper to ground at least the same dielectric strength in the end portion as in the slot portion of the winding. The end portions of the insulated coils are properly spaced for ventilation of the winding, and this spacing helps to reduce the gradients in the coil insulation at these points.

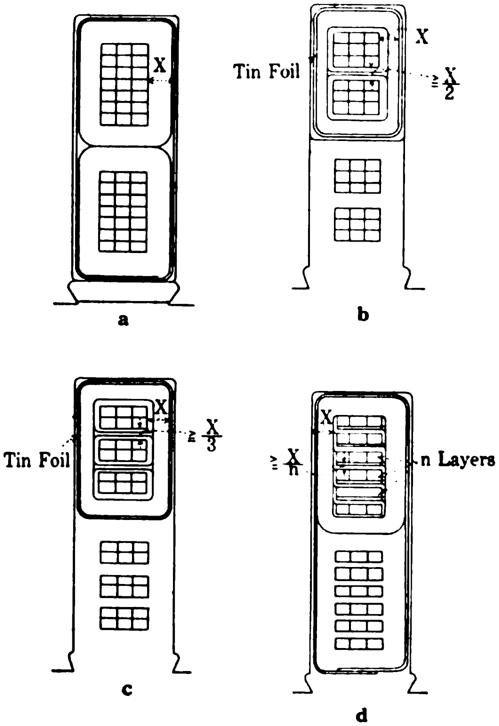

Fig. 4—Armature Coils of Barrel Type Winding

The coil insulation, being of laminated form, is built up of suitable materials, such as paper and mica, varnished cambric, oiled linen, or micanite, cemented together with some binding sticker and built up to the proper thickness to meet the operating voltage.

Method of Calculating the Stress on the Entrapped Air in Coils with Practical Example. As a simple example, take a coil insulated with a uniform, homogeneous insulation of a thickness X and permittivity k. It is sufficiently accurate to assume the conductor of the coil as a flat plate and the iron core or tinfoil as the other plate. The thickness of the entrapped air bubbles will then be so extremely small compared to X that the capacity or total flux will not be appreciably changed thereby.

If the voltage is E,

$$g_i = \frac{E}{X} = \text{gradient in the solid insulation,}$$

$$g_1 = k\frac{E}{X} = \text{gradient in the air bubbles.}$$

A coil, however, is not usually insulated in the above manner, but by a number of wrappings of a composite tape made up of laminae of various solid insulations, a "sticker", and possibly *very thin films of air,* usually much less than one mil thick, between the laminae. These very thin films need not be considered from the standpoint of dielectric strength, since they are very strong as can be ascertained by examining the curve giving the value of G_0 in Fig. 1A. One mil thickness of air has the strength of 354 volts per mil at $t = 25$ deg. cent. and $b = 76$ cm., a value which is approximately equal to the strength of the varnished cambric or paper and mica taping. There are other more or less avoidable local air bubbles, or pockets, of larger thickness, which are due to imperfect butt joints of the tape, due to occasional wrinkles produced by unequal tension during the taping, and due to bulging of the coil insulation, whose strength requires attention. The very thin air films between laminae must be considered, however, in calculating the resultant permittivity, K, since they reduce the dielectric flux density in the coil insulation.

Calculation of the stresses in any of the insulation materials of the combination may then be made from equation (5),

$$g_i = \frac{E}{k_i\left(\frac{X_1}{k_1} + \frac{X_2}{k_2} + \ldots + \frac{X_i}{k_i} + \ldots + \frac{X_n}{k_n}\right)} \tag{5}$$

For convenience let us substitute for the expression in the parenthesis in the above denominator

$$\left(\frac{X_1}{k_1} + \frac{X_2}{k_2} + \ldots + \frac{X_i}{k_i} + \ldots + \frac{X_n}{k_n}\right)$$

$$= \sum_1^n \frac{X_i}{k_i} = \frac{X}{K} \tag{8}$$

where X is the total thickness of insulation

$$X = X_1 + X_2 + \ldots + X_i + \ldots + X_n = \sum_1^n X_i \tag{9}$$

and K is the resultant permittivity

$$K = \frac{X}{\sum_1^n \frac{X_i}{k_i}} \tag{10}$$

The method of calculating the resultant permittivity, K is best shown by an example. Let a taping be made up as follows:

$X_1 = 1$ $X_2 = 4$ $X_3 = 6$ $X_4 = 1.5$ mils

$k_1 = 1$ $k_2 = 2.6$ $k_3 = 5.5$ $k_4 = 4.5$

$X = X_1 + X_2 + X_3 + X_4 = 1 + 4 + 6 + 1.5 = 12.5$

$$\sum_1^n \frac{X_i}{k_i} = \frac{X_1}{k_1} + \frac{X_2}{k_2} + \frac{X_3}{k_3} + \frac{X_4}{k_4}$$

$$= \frac{1}{1} + \frac{4}{2.6} + \frac{6}{5.5} + \frac{1.5}{4.5} = 3.96$$

$$K = \frac{X}{\sum_1^n \frac{X_i}{k_i}} = \frac{12.5}{3.96} = 3.15$$

The resultant permittivity is calculated in Table II for several insulation units. It will be seen that the resultant permittivity, K, of the coil insulation with reference to a temperature of 25 deg. cent. is about 3 to 3.5 for the various tapings and about 4 for micanite.

The resultant permittivities, K, in Table II apply for a

TABLE II

RESULTANT PERMITTIVITY $K = \frac{X}{\sum_{1}^{n} \frac{X_i}{k_i}}$ OF COIL INSULATION-UNITS BASED ON PERMITTIVITIES k_i OF DIELECTRICS AT A TEMPERATURE OF 25 DEG. CENT.

Insulation unit	Composed of materials	X_i Thickness in mils	k_i Permittivity at 25 deg. cent.	$\frac{X_i}{k_i}$ at 25 deg. cent.	$\frac{X}{\sum_{1}^{n} \frac{X_i}{k_i}} = K$ at 25 deg. cent.
One half lap	Paper	4	2.6	1.54	$\frac{12.5}{3.96} =$
taping with	Pasted Mica	6	5.5	1.09	
(.005)" = .001 + .003 + .001	Sticker	1.5	4.5	.33	= 3.15
Paper-Mica-Paper Tape	Air	1	1.0	1.0	
	Total	12.5		3.96	
One half lap	B. V. C.	24	3.8	6.30	$\frac{27}{7.66} =$
taping with	Varnish	2	5.6	.36	
(.012)" Black Varnished	Air	1	1.0	1.00	
Cambric Tape	Total	27		7.66	= 3.52
One half lap	B. V. C.	16	3.5	4.57	$\frac{19}{5.93} =$
taping with	Varnish	2	5.6	.36	
(.008)" Black Varnished	Air	1	1.0	1.00	
Cambric Tape	Total	19		5.93	= 3.2
One half lap	Cotton Tape	10	2.6	3.84	$\frac{15}{5.55} =$
taping with	Varnish	4	5.6	.71	
(.005)" Cotton Tape	Air	1	1.0	1.00	
+ 2 Coats of Varnish	Total	15		5.55	= 2.7
One butted taping	Cotton Tape	5	2.6	1.92	$\frac{9.5}{3.13} =$
with (.005)" Cotton	Varnish	4	5.6	.71	
Tape + 2 Coats of	Air	.5	1.0	.50	
Varnish	Total	9.5		3.13	= 3.03
Micanite			4.0		
Horn Fibre, varnished			2.8		
Press Board, varnished			3.7		

temperature of 25 deg. cent.; at higher temperatures these values become greater, because the permittivities of the solid dielectrics increase with temperature.

From equations (8) and (5) we obtain now

$$g_i = \frac{E}{k_i \frac{X}{K}} = \frac{K}{k_i} \frac{E}{X} \tag{11}$$

and for air $k_i = k_1 = 1$ and $g_i = g_1$

$$g_1 = K \frac{E}{X} \tag{12}$$

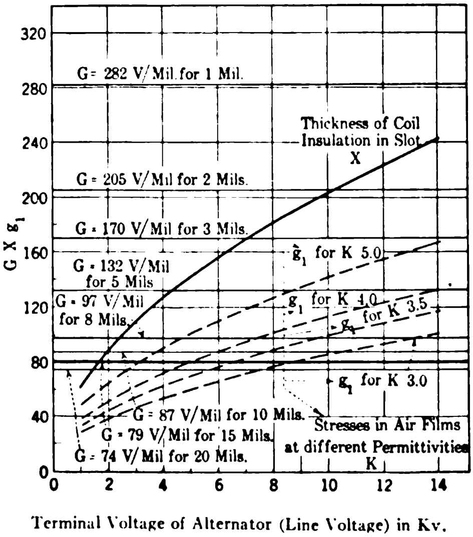

FIG. 5—INVESTIGATION OF START OF CORONA IN COIL INSULATION SHOWN BY A TYPICAL CURVE X

X = Thickness in mils of coil insulation in slot portion (from copper to ground).
g_1 = Dielectric stress in effective volts per mil of entrapped air pockets
G = Dielectric strength of air films at 100 deg. cent. expressed in effective volts per mil

where g_1 = dielectric stress or gradient in air bubbles or pockets, expressed in effective volts per mil;
K = resultant permittivity of the coil insulation;
E = effective sine wave voltage between line terminal and core or grounded tinfoil, expressed in volts = line voltage $/\sqrt{3}$;
X = thickness of coil insulation in slot portion measured from copper to core or grounded tinfoil and expressed in mils;

In case of composite coil insulation which is made up of several layers of different kind of insulation—units, as layer *A* next to the coil, then *B*, then *C*, having layer thicknesses X_A, X_B, and X_C and resultant permittivities K_A, K_B and K_C respectively, the resultant of the resultant permittivities is

$$K = \frac{X}{\frac{X_A}{K_A} + \frac{X_B}{K_B} + \frac{X_C}{K_C}} \qquad \textbf{(13)}$$

TABLE III

DIELECTRIC STRESSES IN AIR FILMS IN COIL INSULATION SHOWN BY CURVE *X* IN FIG. 5.

Line Voltage	Potential to ground	Thickness of coil insulation in mils		Calculated gradients in volts per mil in air films of coil insulation $g_1 = K \frac{E}{X}$ for			
$\sqrt{3}E$	E	X	$\frac{E}{X}$	$K = 3$	$K = 3.5$	$K = 4$	$K = 5$
1,000	577	60	9.6	29.0	34	38	48
2,000	1,154	88	13.1	39	46	53	66
3,000	1,731	110	15.8	47	55	63	79
4,000	2,310	128	18.0	54	63	72	90
5,000	2,885	143	20.2	61	71	81	101
6,000	3,460	157	22.0	66	77	88	110
7,000	4,045	170	23.8	71	83	96	119
8,000	4,620	182	25.4	76	89	102	127
9,000	5,200	193	27.0	81	95	108	135
10,000	5,770	204	28.3	85	99	113	142
11,000	6,350	215	29.6	89	104	119	148
12,000	6,930	225	30.8	93	108	123	154
13,000	7,500	233	32.2	97	113	129	161
14,000	8,090	241	33.6	101	118	135	168

where K_A, K_B and K_C are obtained from equation (**10**) or from Table II for the corresponding insulation-unit in the layer *A*, *B* and *C* respectively.

In Fig. 5 is given a typical curve, *X*, showing the thickness of coil insulation in the slot portion of alternator windings—in relation to the terminal voltage (line voltage).*

In Table III this curve is analyzed with respect to the dielectric stresses in air pockets in the coil insulation, by applying equation (**12**) and using the resultant permittivities $K = 3$, 3.5, 4 and 5 respectively.

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*See Standard Handbook for Electrical Engineers, Fourth Edition, Section 7, Alternating Current Generators and Motors by Comfort A. Adams and Henry M. Hobart, page 484, Fig 65.

The stresses g_1 in air bubbles for different resultant permittivities, K, are shown in the relation to the terminal voltage by the broken curves in Fig. 5.

In Fig. 6 is reproduced the curve of dielectric strength G_0 of air at $t = 25$ deg. cent. and $b = 76$ cm. in relation to spacing, (see also Fig. 1A), and therefrom is derived—by applying equations (**1**) and (**2**)—the curve of dielectric strength G of air films at $t = 100$ deg. cent. and $b = 76$ cm.

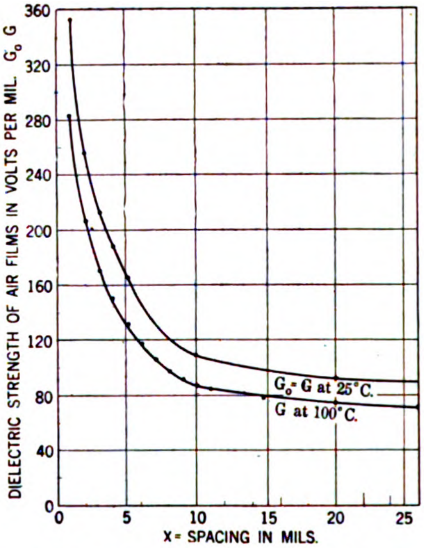

FIG. 6—DIELECTRIC STRENGTH OF AIR FILMS AT $b = 76$ CM. AND $t = 25$ AND 100 DEG. CENT. RESPECTIVELY

The following values of dielectric strength, G, of air at $t = 100$ deg. cent. and $b = 76$ cm. for spacings; $X_1 =$ 1, 2, 3, 5, 8, 10, 15, 20 mils; namely $G =$ 282, 205, 170, 132, 97, 87, 79, 74 volts per mil are shown by lines parallel to the abscissa axis in Fig. 5 and *their intersections with the broken curves* g_1 *indicate the starting points of the corona* in the entrapped air bubbles or pockets.

As stated above we have to consider the strength of entrapped air bubbles or pockets of larger thickness only, namely of such air bubbles or pockets which are due to imperfect butt joints of the tape, due to occasional wrinkles produced by unequal tension during the taping, and due to bulging of the coil insulation.

Since air has the lowest value of both permittivity and dielectric strength among the insulating materials which enter into the combination of the coil insulation, we should keep the dielectric stress of those air bubbles or pockets below the critical values which are plotted in Fig. 6 in relation to the air spacing. Both temperature and barometric pressure (altitude) of the location affect the strength of air pockets entrapped in coils, and should be taken into consideration. Tightly wound coils with very thin air pockets withstand higher dielectric stresses than loosely insulated coils.

Let us consider a practical example to illustrate the use of Fig. 5.

Take a 13,200-volt generator. Assume that $K = 3.5$ at 100 deg. cent. and that the method of manufacture is such that there is a probability of 10 mils air pockets in the coil insulation. From curve X the thickness of coil insulation for a 13,200-volt generator is 235 mils from copper to core or grounded tinfoil. The stress on the entrapped air for $K = 3.5$, from the broken curve g_1 for $K = 3.5$, is $g_1 = 113$ volts per mil.

The dielectric strength of 10 mils air pocket at 100 deg. cent., as indicated by the horizontal line $G = 87$ volts per mil for 10 mils, air film, is not strong enough to withstand a stress of $g_1 = 113$ volts per mil, with the result that there will be corona in the 10 mils air pockets.

If the method of manufacture can be improved so that the air bubbles in the coil insulation are all reduced to about 5 mils or less, there will be no internal corona, since the strength of a 5 mils pocket is then 132 volts per mil, as indicated by the horizontal line $G = 132$ volts per mil for 5 mils air film.

The above can, of course, also be calculated for any coil insulation directly from equation (**12**) and the conclusion reached by inspection of Fig. 6.

It should be borne in mind that we have considered so far the dielectric stresses in air in a uniform electric field, which is nearly the case for the sides of the coils adjacent to the core. At the edges produced in the slots by the air ventilating ducts in stator iron and at the edges of the coils, layers and turns, there are some concentrations of the dielectric field which produce somewhat higher local stresses on the coil insulation and the occluded air pockets than at the location of the uniform field.

The edges of stator ducts and stator teeth may produce external corona and cause pitting of the coil insulation at the coil surface. This danger can be guarded against by providing a grounded tinfoil armor extending 1½ to 2 in. at each end beyond the slot portion of the coil. The coil insulation must be properly reenforced under and above the edges at the ends of the tinfoil armor.

The edges of layers and turns are locations of increased stress for the internal coil insulation between layers and turns. The problem is comparatively simple for coils which have but few turns per coil with only one turn per layer. Here the turns may be heavily taped, as shown in Figs, 4B and 4C without much loss of space, because the turn insulation constitutes a part of the coil insulation. It is recommended that coils with n turns per coil receive an insulation between turns equal to at least $1/n$ of the thickness of the coil insulation to ground. Such turn insulation will stand up indefinitely under normal operating conditions and will also withstand occasional line surges when they penetrate the winding. It is in most cases the insufficient turn insulation that, after comparatively short operation, ages and deteriorates due to action of internal corona, and causes break down usually in the line coil.

Coils wound with several layers and several turns per layer are more delicate and must be insulated yet more liberally to withstand safely a long time service. Such coils are usually filled with compound before the insulation is applied; the purpose of this treatment is to eliminate so far as possible all the air between turns and layers inside the coil.

In conclusion it is evident that the dielectric stress on the air bubbles in solid insulation of armature coils should be calculated and kept below the dielectric strength by using suitable thickness of insulation for the required operating voltage and by applying the insulation as tightly as possible. The internal insulation of coils between layers and turns should be adequate and selected in proper relation to the coil insulation to withstand the increased dielectric stresses at the edges of layers and turns and to withstand the line surges.

General Description of Insulation in Cables and Leads. The insulation of cables and leads is also of laminated form, being built up of paper or varnished cambric tape, and occludes also thin air bubbles or pockets. The latter are, of course, much thinner than those in the coil insulation, because the taping of the cylindrical conductor can be done with uniform tension; and in the case of cables the taping is applied with a machine.

The dielectric problems with which we will deal here are, therefore, similar to those encountered in the coil insulation, except that the electric field in the cable insulation is not uniform, but radial,—as shown in Fig. 7.

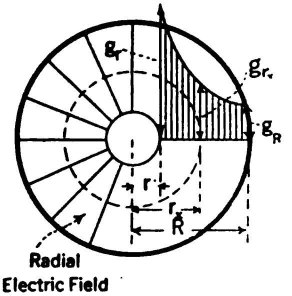

FIG. 7—SINGLE CONDUCTOR CABLE WITH LEAD SHEATH

Let

r = radius of wire in mils,

r_x = any radius of the insulation around the conductor in mils,

R = inside radius of the lead sheath in mils,

E = effective sine-wave voltage between the conductor and the grounded lead sheath,

g_r = gradient in effective volts per mil on the cable insulation at radius r,

g_{r_x} = gradient in effective volts per mil on the cable insulation at radius r_x.

g_R = gradient in effective volts per mil on the cable insulation at radius R.

The following equations hold for the gradients at different points in the radial electric field of a homogeneous insulation:

$$g_r = \frac{E}{r} \frac{1}{\log_e \frac{R}{r}} \tag{14}$$

$$g_{r_x} = \frac{E}{r_x} \frac{1}{\log_e \frac{R}{r}} \tag{15}$$

$$g_R = \frac{E}{K} \frac{1}{\log_e \frac{R}{r}} \tag{16}$$

If K is the resultant permittivity of the cable insulation, we may determine the dielectric stresses $g_{1,r}$, g_{1,r_x}, $g_{1,R}$ on occluded air pockets at different points in the radial electric field as follows:

$$g_{1,r} = K g_r = K \frac{E}{r} \frac{1}{\log_e \frac{R}{r}} \tag{17}$$

$$g_{1,r_x} = K g_{r_x} = K \frac{E}{r_x} \frac{1}{\log_e \frac{R}{r}} \tag{18}$$

$$g_{1,R} = K g_R = K \frac{E}{R} \frac{1}{\log_e \frac{R}{r}} \tag{19}$$

The gradient g_i, r_x, in any dielectric of permittivity k_i at any radius r_x, can be calculated from the following equation:

$$g_i, r_x = \frac{K}{k_i,} \frac{E}{r_x} \frac{1}{\log_e \frac{R}{r}} \tag{20}$$

In case that the cable insulation is made up of one insulation-unit the K for equations (**17**), (**18**), (**19**) and (**20**) can be obtained with sufficient approximation from equation (**10**) or from Table II for the corresponding insulation-unit.

In case that the cable insulation is graded by using several layers of different kind of insulation-units, as layer A next to the conductor of radius r, then B, then C, having outside radii R_A, R_B and R_C and resultant permittivities K_A, K_B and K_C respectively, the resultant of the resultant permittivities, K, for equations (**17**), (**18**), (**19**) and (**20**) is

$$K = \frac{\log_e \frac{R_C}{r}}{\frac{1}{K_A} \log_e \frac{R_A}{r} + \frac{1}{K_B} \log_e \frac{R_B}{R_A} + \frac{1}{K_C} \log_e \frac{R_C}{R_B}} \tag{21}$$

where K_A, K_B and K_C are obtained from equation (**10**) or from Table II for the corresponding insulation-unit in the layer A, B and C respectively.

The gradient $g_{1,r}$ on the air pockets at the conductor radius r has the maximum value because it occurs in the densest electric field.

From equation (**17**) it will be seen that the occluded air is subjected to a higher dielectric stress than the solid insulation. Because the dielectric strength of the air bubbles is lower than the dielectric strength of the solid insulating materials which enter into the combination of the cable insulation, we should, to avoid corona, keep the dielectric stress, $g_{1,r}$ on the air pockets, below the critical values which are plotted in Fig. 6 in relation to air spacing.

Conclusions from the Applications in Part II. To avoid corona in the insulation of armature coils, cables and other high-tension apparatus operating in air, it is necessary that under normal operating conditions the dielectric stress on air is below the dielectric strength of such air spaces, air bubbles or pockets which cannot be avoided in the process of manufacture.

A solid insulation which is not subjected to corona will show not an abnormal deterioration with time but will preserve practically its full dielectric strength and enable it to withstand exceptional high voltage stresses of very short duration, caused by surges and lightning.

This discussion does not cover, of course, the phenomenon generally known as "aging", that is the fatigue of solid insulations with time due to slow oxydation in the atmospheric air, or from effects of heating and dielectric stress below corona starting point.

It is not within the scope of this paper to deal with the difference in action between air films or thin pockets which have a practically uniform dielectric field and air bubbles or air spaces of such a shape as to distort the field. The latter may introduce additional phenomena as lateral stresses at the surface of division of air and taping.

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IONIZATION OF OCCLUDED GASES IN HIGH-TENSION INSULATION

BY G. B. SHANKLIN AND J. J. MATSON

Abstract of Paper

This paper deals with the ionization of occluded gases in solid insulation from the standpoint that these gas spaces are the weakest part of an insulation design and should receive first consideration. The stress at which ionization starts in different types of built-up insulation, such as used in cables and coils, is measured and from these measurements a safe working stress determined. The paper brings out, more than anything else, the importance of reducing the gas spaces to a minimum size, and using materials of the lowest possible permittivity, since the higher the permittivity the greater the stress on the gas spaces.

If an insulation design is worked at a stress so high that internal ionization occurs it should be considered as "over-stressed" and its life will certainly be shortened. Just how much it will be shortened depends upon such factors as; type of insulation used, degree of over-stressing, looseness and porosity, etc. Roughly, the life of an over-stressed design is any where from six months to six years, judging from numerous tests made. This shows that the damage is very gradual.

Introduction

The selection of a safe voltage rating for high-tension equipment, such as cables and coils, or more properly speaking, the selection of a safe thickness of insulation, has not, like other factors in electrical engineering, been based on scientific grounds. The method of selection has been more a question of judgment and experience, than any thing else.

It is generally admitted that high-potential testing and dielectric strength data are very unsatisfactory criterions. They are of value only in testing for flaws and defects. But assuming the insulation in perfect condition physically and as having a dielectric energy loss sufficiently low at maximum operating temperature to assure against accumulative heating or undue rise in temperature, no satisfactory method of predetermining the proper thickness has been available.

In studying the service strength of any design the weakest

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point has first consideration. Occluded gas is the weakest point of insulation designs, such as considered above. The solid insulation alone, always assuming, of course, that it is a good grade of material and workmanship, will safely withstand much greater stress than when occluded gases are present. When the stress is high enough to ionize these gases, the insulation should be considered "over stressed." This has been generally recognized but the fact that occluded gas is, almost without exception, inherent in organic insulation has received little recognition.

It is the purpose of this paper to present the results of an extensive study of these gas spaces and the effects they introduce. In doing so we do not wish to over emphasize the importance of this one factor. What we do wish to emphasize is that this method of study or test fills a breach in insulation engineering. The method of "judgment and experience" has, as is usually the case, given correct results. It is interesting to note in studying the data given in this paper how closely the maximum allowable working stress agrees with that which is accepted as good practise.

Occluded Gas and its Causes

There are so many variables that enter into the formation and characteristics of gas pockets, from the most minute pocket to the largest, that it is impossible to give a complete analysis at the present stage of the investigation. A certain amount of speculation, although an effort will be made to reduce it to a minimum, must be indulged in.

Each detail in the process of manufacture and application of materials introduces some new factor into the formation of gas spaces. Quite often the methods of installation and operation introduce additional factors.

Impregnated Paper Cable, is usually made by first wrapping dry paper tape around the conductor. To simplify the illustration, single-conductor, lead-sheath cable only will be considered.

The dry paper cable is put into a vacuum tank and the greater part of the moisture and air extracted under heat. It is not a perfect vacuum and a certain amount of impure air remains. Melted filling compound is then let into the tank until the cable is immersed. The compound acts as a valve and stops up all the exposed passages through the paper wrappings. Pressure is then applied and the compound forced thoroughly into the cross section. The slight amount of impure air remaining in the cable is driven back into the cross section and entrapped in the spaces or voids between wrappings. The applied pressure compresses these gas spaces to a most minute size.

After the cable has been in the tank long enough to assure complete impregnation the pressure is reduced to atmospheric and the heat cut off. The gas spaces thereby automatically expand to atmospheric pressure and remain at this pressure during cooling. After the cable has cooled down to a temperature at which the compound is somewhat thickened but still thin enough to drip it is lifted out and the excess compound cleaned off. The cable is lead jacketed while still warm and is then immune from external pressure except through the ends. Every one is familiar with the exuding of compound from the exposed ends of cable when heated. This is due to a tendency to equalize the pressure inside and out.

When the cable has cooled to a temperature of about 55 deg. cent. or lower, depending upon the type of filling compound, the compound has thickened to such an extent that pressure is not transmitted to the gas spaces and their size remains constant at lower temperatures, except for the slight enlargement that occurs due to shrinkage of the compound.

At room temperature, then, the pressure in the spaces must be something less than atmospheric. Assuming the temperature at which the compound thickens as 55 deg. cent. the pressure at 25 deg. cent. should be approximately,

$$\frac{760\ (273 + 25)}{273 + 55} = 690 \text{ mm.},$$

or allowing 4 per cent for shrinkage of compound, about 650 mm.

In speculating upon where these spaces are distributed we are inclined to believe that the greater percentage of them are initially down towards the center of the cross section, near the conductor. They are forced down into the cross section by the entrance of the impregnating compound. Either this is the case or the whole cross section contains a maze of gas spaces, for the test results invariably show spaces in the neighborhood of the conductor, where maximum stress occurs.

The aim should be always to keep these spaces reduced to a minimum, for the larger spaces are, the less the stress required to ionize the gas. It is obvious that the paper wrappings should be tight and compact. This prevents the gas from accumulating at one point in the filling compound and forming a bubble of appreciable size between loose layers of paper, or in creases or crinkles.

Varnished Tape and Sheet Materials. The conditions under which these are applied and treated is somewhat different from cable paper. Usually they are wrapped on while exposed to the room air. Varnish or shellac is brushed on between wrappings to stick them together and fill up space. It is reasonable to expect that some air will be entrapped during this application and is originally at atmospheric pressure. When the material is baked or dried out the volatile solvent joins with the air to set up considerable internal pressure and this forces passages through the thickness so that the gases can escape. A cured material is consequently more or less porous and the gas pockets all have small capillary passages to the surrounding atmosphere. They are, then, normally at atmospheric pressure and it is possible to supply fresh air through the outlet passages as the material cools down. This is called "breathing."

If the tapings or sheets are applied tightly to conductors of round cross section the thickness of the gas spaces should be about in the same order as those experienced in well wrapped paper cables. If, however, the material is applied to conductors of rectangular cross section the thickness of the spaces might vary anywhere between those found in round cross sections and values much greater, depending upon the type of insulation considered, the process of application, conditions of use, etc. There is a tendency for the insulation to bulge away from the rectangular sides, which accounts for the wider variation in thickness of gas space.

IONIZATION CURVES

The loss introduced by ionization of occluded gases is combined with the inherent dielectric loss of the solid material and in obtaining data it is necessary to measure the total loss. Fortunately the ionization loss is an appreciable part of the total and is easily and accurately distinguished.

The dielectric energy loss measurements were made by the "Compensated Dynamometer Wattmeter Method." This was described in detail in an article published previously.[1]

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[1] "Compensated Dynamometer Wattmeter Method of Measuring Dielectric Energy Loss," G. B. Shanklin, *General Electric Review*, Oct. 1916.

A better conception of the method, its accuracy and the way the data are worked up and analyzed can be obtained from a paper read before the Institute in June, 1917.[2]

During the three years in which we have followed this work all possible precautions have been taken to eliminate external sources of loss, phase-angle errors and other forms of inaccuracy. Numerous checks have been made besides those described in the two publications referred to. Familiarity with the method and analysis of a mass of data make us feel that an accuracy better than 2 per cent is obtained at the lowest dielectric power factors ordinarily met with in solid materials.

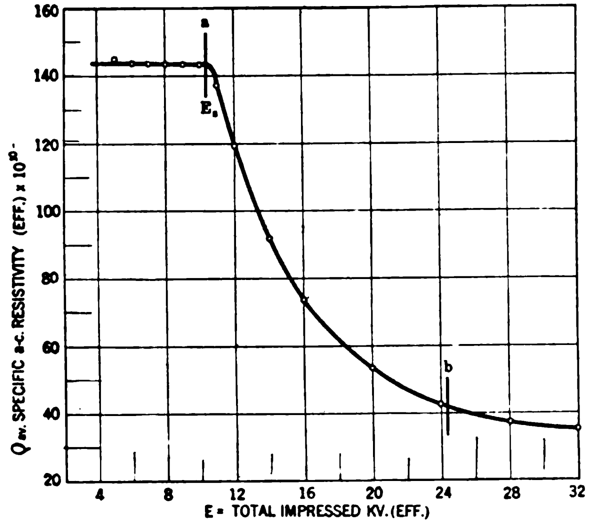

FIG. 1—TYPICAL IONIZATION CURVE

A typical ionization curve is given in Fig. 1. It is calculated from 60-cycle energy-loss data taken at room temperature on a 2/0 single-conductor cable with 9/32 in. thickness of impregnated paper and lead sheath. The watts and current were measured at the impressed voltages indicated. From these readings the effective a-c. restivity per cm^3 ($\rho_{av.}$, average through the thickness) was calculated by formula (1) in the Appendix.

Let it be assumed that there are gas spaces sparcely scattered throughout the cross section of cable and that the thicknesses of these spaces vary from zero to that of the largest met with. Up to 10.3 kv. (a) the loss represented by $\rho_{av.}$ is the inherent dielectric loss of the solid material and varies practically as the square of the voltage. The largest gas spaces next to the conductor are the first to be ionized. The voltage gradient at the conductor (in the solid material, not in the gas space) will be

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[2] "Insulation Characteristics of High-Voltage Cables," Clark and Shanklin, A. I. E. E. TRANS., Vol. XXXVI, 1917, p. 447.

$$g_{max.} = \frac{E}{a \log_\epsilon b/a} = 2.218\ E,$$

and since $E_n = 10.3$ kv., $g_{max.} = 22.8$ kv. per cm.

As the voltage is gradually raised the gradient at the conductor increases and the smaller spaces at this point will be ionized. Likewise, the gradient 22.8 kv. per cm. is traveling out through the thickness ionizing the larger spaces until it finally reaches the sheath at an impressed voltage $E = 24.3$ kv. (b). Complete saturation is not yet reached but the curve is flattening out, showing that the majority of the gas spaces have been ionized. It is impossible to reach complete saturation before the cable breaks down as the extremely small gas spaces, those of microscopic dimensions, require excessive stress to ionize them.

Another factor that determines the slope of these curves is the increase in gas pressure after ionization once starts. This increase in pressure, or "ionization pressure" as it is called, is dealt with in books on gases by J. J. Thompson[3] and J. S. Townsend.[4] A paper by E. H. Warner[5] also covers the subject.

Since the gas pressure at the instant ionization starts is that with which we are dealing, the "ionization pressure" does not bear on our work, but it is mentioned merely as a matter of interest.

The relative permittivity ($K_{av.}$, average through thickness) is calculated from the energy-loss data by formula (**2**) in the Appendix. For a full description of these characteristics reference should be made to the Institute paper previously referred to.

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[3] "Conduction of Electricity through Gases," by J. J. Thompson, Cambridge Press, 1906.

[4] "Electricity in Gases" by J. S. Townsend, Oxford Press, 1915.

[5] "Ionization Pressure, by E. H. Warner, *Phys. Review*, Vol. 8, 1916, p. 285.

$K_{av.}$ is not the true relative permittivity. In calculating $K_{av.}$ it is assumed that the dielectric circuit is a parallel circuit, that is, the leakage path (a-c.) and capacity are assumed in parallel. Actually the circuit is a maze of series-parallel paths. The series component determines the change in $K_{av.}$ with frequency, depending upon the type of material considered. For instance, in varnished cambric or impregnated paper the difference in $K_{av.}$ at 25 and 60 cycles is small, especially at higher temperatures, because the series component is small. In pasted mica the difference is greater due to the "barrier effect" of the mica flakes.

$K_{av.}$ is an average effective value through the whole thickness and is consequently the value needed in this work. It corresponds to the effective a-c. resistance of a conductor in which skin effect is appreciable. The true permittivity corresponds to the d-c. resistance of the conductor.

Knowing the effective permittivity of the solid insulation and the voltage at which ionization begins, curves can be calculated showing the stress across gas spaces of any assumed thickness. Also, knowing approximately the pressure of the gas and its dielectric strength, cross curves can be plotted and a comparison will indicate the maximum thickness of gas space. This method of dealing with the data will be followed throughout the paper. It would be impossible to present all of the energy-loss data or even the ionization curves alone, as hundreds of them were taken.

In a number of cases measurements were taken at both 25 and 60 cycles. The voltages at which ionization started agreed almost exactly. In other words, the ionization starting point is practically independent of frequency over the usual commercial range.

During the initial stages of this work considerable difficulty was experienced in obtaining uniformly smooth and consistent curves, such as that shown in Fig. 1. In particular, the points taken at the lower voltages would not line up on a smooth curve but plotted in a haphazard manner. We at first came to the conclusion that the ionization was inherently unstable and followed no simple law, but further investigation showed this trouble to be due to two causes:

1. The errors in voltage reading are squared in the calculation of $\rho_{av.}$ and come in once more in the abscissas of the curves. The greatest possible accuracy in voltage reading over the whole range is therefore necessary.

2. The wave shape varied slightly over the voltage range. This not only changed the values of ρ_{av}. but also gave an ionization starting point at variance with that of a sine wave. This error was corrected by connecting a relatively large capacity in parallel with the test sample. A pure sine wave over the whole voltage range resulted.

The effects of a badly distorted wave are shown in Fig. 2 the data being taken at 60 cycles, room temperature, on a sample of mica-paper insulation 0.16 in. thick, wrapped on a conductor of rectangular cross section. Baking at high temperature had caused the insulation to loosen up and form numerous gas spaces. Curve (*a*) shows measurements with a distorted wave and curve (*b*) with a sine wave. Oscillographic records of the two waves are shown in Fig. 3. The higher harmonics in (*a*) were caused by an iron core reactance in the low voltage side. Wave shape (*b*) was taken after 0.05 microfarads capacity was connected in parallel with the test sample.

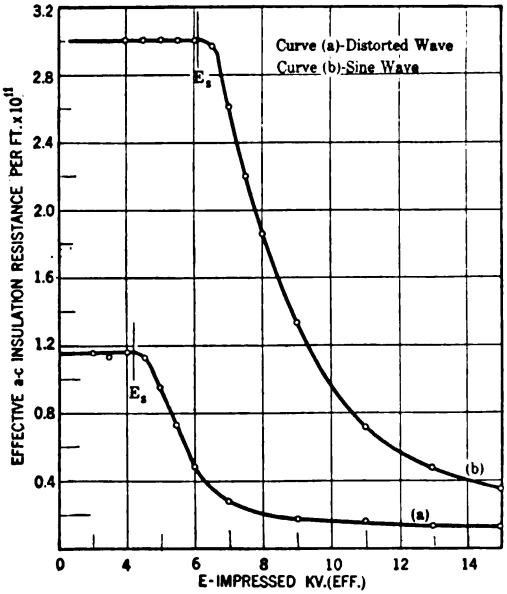
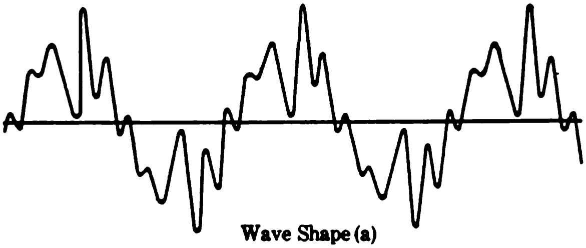


Fig. 2—Ionization Curves Showing Effect of Distorted Wave Shape

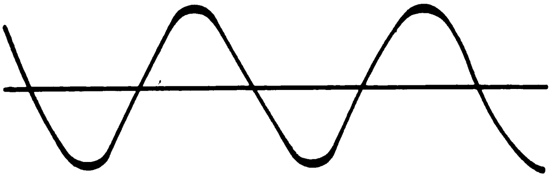
Ionization starts at 6.1 kv. effective with the sine wave, while with wave (*a*) it starts at 4.2 kv. The starting point with wave (*b*) is $6.1 \times \sqrt{2} = 8.62$ kv. maximum, with wave (*a*) it is $4.2 \times 2.03 = 8.53$ kv. maximum. These two values correspond closely.

STRENGTH OF AIR

Before the thickness of gas space in a test sample, can be determined the strength of gas under exactly the conditions, met with must be known. From the nature of these conditions the gas considered must be a mixture of air and the volatile organic contents of the insulation, the amount of impurity depending upon the vapor tension of the different components, the ability to supply fresh air to the gas spaces, etc.



Wave Shape (a)



Wave Shape (b)

FIG. 3—OSILLOGRAPH RECORDS OF WAVE SHAPES REFERRED TO IN FIG. 2

In those cases where components of low vapor tension, such as benzol, are present the nature of the conditions is such that passages are forced from the gas pockets to the outside air and the impurities mostly escape.

Impregnating compounds are heat or vacuum treated before using, and their components have a comparatively high vapor tension. When impregnating compound is admitted to the filling tank the vacuum decreases but little faster than the decrease in gas volume, which shows that the amount of impurity liberated is not great.

We can say roughly, that, the occluded gas in insulation is a mixture of air and from zero to about 50 per cent impurity, the impurity as a general rule being an organic vapor. The best that can be done is to consider the strength of air alone. The amount of impurity will vary in different cases and complete ionization data is available only for air.

On pages 466 to 471 of J. J. Thompson's book he discusses and analyzes data on various gases and vapors. The strength of CO_2 and water vapor is about equal to that of air over the range of pressure and gap spacing needed in our work. The strength of benzol vapor varies from about 1.0 to 2.5 times that of air.

TABLE I

DIELECTRIC STRENGTH OF AIR BETWEEN PARALLEL PLATES

P = pressure in mm.
t = air gap in mm.

$P \times t$	Volts Eff. A-C.	$P \times t$	Volts Eff. A-C.	$P \times t$	Volts Eff. A-C.
1.05	1371.5	9.0	260.0	160.	1025.
1.10	1226.5	10.0	270.0	200	1195
1.35	813.0	15.0	308.0	300	1602
1.50	686.0	20.0	336.5	400	1980
2.00	452.5	25.0	363.0	500	2350
2.50	346.5	35.0	417.5	600	2705
3.00	295.5	45.0	471.5	800	3402
4.00	254.5	60.0	554.0	1000	4075
5.00	249.0	80.0	664.0	1200	4720
6.00	249.5	100.0	756.0	1500	5655
7.00	250.0	120.0	848.0	1700	6260
8.00	252.0	140.0	937.0		

In discussing Bouty's tests on different gases between glass plates, Thompson concludes that the nature of the electrodes (whether metal or dielectric material) has no effect unless the spacing is comparable with the mean free path of the gas molecules. Tests in our laboratory at 60 cycles, atmospheric pressure, showed no difference in the strength of air between brass electrodes and glass plate electrodes down to the minimum spacing (0.05 cm.) that could be measured accurately.

Table No. 1 gives the strength of air in terms of Pachen's Law;

$$Pt = \text{a constant voltage.}$$

where P = mm. pressure, and
t = mm. gap spacing.

The data in this table represent an average of the values obtained by a number of investigators with both direct and alternating voltages. Most of the data were taken from the books by J. J. Thompson and J. S. Townsend. In some cases original sources were referred to.[6]

Pashen's Law as given above is based on the assumption that $P \times t =$ a constant mass of gas per unit area of gap. Also, the figures in Table I are based on an air density equivalent to a temperature of 25 deg. cent.

It is obvious that when increasing the temperature of a test sample above 25 deg. cent. this condition is not met with. A correction can be made, however, if the gas pressure and temperature are known. Harris[7] has shown that a change in air density produced the same effect on dielectric strength whether due to temperature or pressure.

In paper cables, for instance, the gas pressure is assumed as 650 mm. at 25 deg. cent. and 760 mm. above 55 deg. cent., as previously discussed. This can be corrected for by assuming "equivalent pressures" proportional to the absolute temperatures, instead of the actual pressure. The "equivalent pressures" are:

650 mm. at 25 deg. cent.
760 mm. at 55 deg. cent.

$$760 \times \frac{328}{373} = 668 \text{ mm. at 100 deg. cent.}$$

In wrapped insulation that has been cured the gas pressure is assumed as 760 mm. over the whole temperature range. The "equivalent pressures" therefore are:

760 mm. at 25 deg. cent.

$$760 \times \frac{298}{373} = 607 \text{ mm. at 100 deg. cent.}$$

$$760 \times \frac{298}{473} = 479 \text{ mm. at 200 deg. cent.}$$

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[6] "Laws of Elec. Discharge in Gases," by W. R. Carr, Phil. Trans. of Royal Society A, Vol. 201, 1903.

"Comparison of A-C. and D-C. Spark Potentials, by J. C. Jansen, *Phys. Review*, Vol. 8, 1916.

"Dielectric Phenomena in High Voltage Engineering," by F. W. Peek, McGraw-Hill Co., 1915.

[7] W. S. Harris, Phil. Trans. Royal Society, 1834, p. 230.

TABLE II.
SINGLE CONDUCTOR PAPER CABLE:
FILLED WITH MINERAL HYDRO-CARBON BASE COMPOUND. LEAD SHEATH. NEVER IN SERVICE.

Sample No.	Type of conductor	Dia. cond. inches	Thick. insul. inches	G_{max} kv. per cm. at cond.	Temp. deg. cent.	Freq.	K_{av}	E_s Start of ionization kv.	$G_{max.}$ at start kv. per cm.	Remarks
No. 1	stranded	.412	9/32	2.218E	25	60	3.28	10.2	22.65	Wrappings compact and well filled. Inherent loss higher than average.
					50	60	3.30	10.9	24.20	
					75	60	3.45	11.0	24.40	
No. 2	stranded	.412	9/32	2.218E	21.5	60	2.93	10.1	22.40	Wrappings compact but not very well filled. Inherent loss less than average.
					51.5	60	2.96	11.2	24.85	
					73.0	60	2.90	12.0	26.60	
					100.0	60	2.93	13.2	29.30	
No. 3	stranded	1.346	14/32	1.17E	25.0	60	2.85	20.0	23.40	Wrappings compact and well filled. Inherent loss less than average.
					47.5	60	2.87	22.0	25.75	
					72.5	60	2.92	24.0	28.07	
No. 4	stranded	1.186	26/32	.770E	23.	60	3.17	30.0	23.10	Wrappings compact and fairly well filled. Average inherent loss.
					60	60	3.27	31.5	24.25	
					100	60	3.67	33.5	25.80	
					60	25	3.55	31.5	24.25	
					100	25	4.20	33.5	25.80	
No. 5	smooth	1.311	24/32	.7875E	26	60	3.10	28.5	22.45	Conductor surface smoothed with 1/16 in coating of lead. Wrappings compact and fairly well filled. Average inherent loss.
					60	60	3.23	32.0	25.20	
					100	60	3.70	32.75	25.80	
					28	25	3.30	29.0	22.85	
					60	25	3.50	32.5	25.60	
					100	25	4.20	33.0	26.00	
					SAMPLE WITH LARGE GAS SPACES.					
No. 6	stranded	1.186	22/32	863.E	23.5	60	2.91	15.0	12.95	Wrappings loose and badly wrinkled. Only partly filled. Inherent loss less than average.
					59.0	60	3.05	16.0	13.81	
					97.0	60	3.20	17.0	14.68	
					23.5	25	3.11	15.5	13.38	
					59.5	25	3.24	16.0	13.81	
					98.0	25.	3.68	16.5	14.25	

When determining the strength of air from Table I the "equivalent pressures" should be used instead of the actual pressures.

IONIZATION DATA

Single-Conductor Paper Cable: Filled with Mineral Hydrocarbon Base Compound. Lead Sheath. In Table No. 2 data are given for samples of single-conductor paper cable filled with mineral hydro-carbon base compound. The various cross sections cover a wide range. The voltage at which ionization starts (E_s) was taken from measured curves similar to that in Fig. 1. In every case it is the minimum value measured on two or more separate samples.

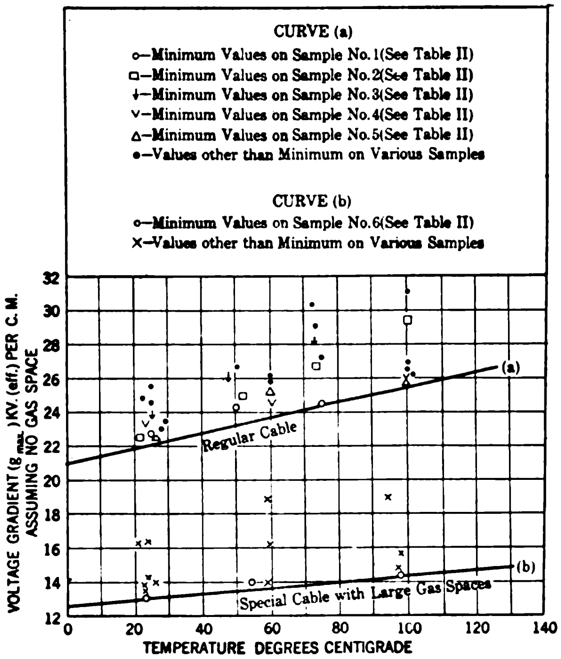

FIG. 4—MAXIMUM VOLTAGE GRADIENT BETWEEN CONDUCTOR AND SHEATH (ASSUMING NO GAS SPACE) AT START OF IONIZATION

Single conductor paper cable—filled with mineral hydro-carbon base compound— new cable; never in service

In Fig. 4 the voltage gradient (effective kv. per cm.) in the solid insulation at the conductor, that is, assuming no gas spaces present, is given for the different cables at the instant ionization starts. The assumption of no gas spaces is allowable, for even when present they are so small as not greatly to effect the distribution of stress in the solid material. Also, it would be expected that the larger number of the stress lines between conductor and sheath pass only through solid material without encountering gas spaces.

The gradient (g_{max}) agrees surprisingly well for the different cross sections. All of the points above curve (*a*) in Fig. 4 are representative of the values met with in ordinary commercial cable of this type. In a number of cases we found values of g_{max} higher than those given in Table II. These are given in Fig. 4 but are not included in the table, as the minimum values are of greater importance. Occasionally there would apparently be no ionization at all above 70 deg. cent.

Extending the minimum curve (*a*) in Fig. 4 back to 0 deg. cent., a temperature lower than would be met with in operation, gives a value of 21. kv. per cm. Allowing a further margin of safety it would appear that 19 or 20 kv. per cm. should be selected as the maximum allowable working stress in a cable of this type, assuming, of course, that the cable is compactly made up and in good condition and further that the working voltage has approximately a sine wave.

Ionization starts in sample No. 5 at the same value of g_{max} as in the other samples. This sample had a smooth surfaced conductor while the others had stranded conductors. We have made a close study of smooth and stranded conductors and have never found any difference between their effects. Either the gas spaces occur slightly out through the thickness of insulation from the conductor, or stranded conductors give a uniform radial stress without appreciable distortion next to the conductor.

It now remains to determine approximately the maximum thickness of gas space met with in this type of cable. Taking sample No. 5 as a representative sample the stress across gas spaces of assumed thicknesses was calculated at 26 deg. and 100 deg. cent. using formula (3) in the Appendix. The stress (g_a) across the gas space is calculated as the average by making $x = a + 1/2\ t_a$ when the gas space is assumed next to the conductor, or $x = b_1 + 1/2\ t_a$ when the space is assumed out in the thickness of insulation, which is allowable because there is only one or two per cent difference between the maximum and minimum stress across the gas space. In other words, the lines of stress across the gas space are practically parallel. This is due to its extreme thinness when compared with radius *a*.

The calculated curves discussed above are given in Fig. 5. The gas space (t_a) is first assumed as next to the conductor and then 5 and 15 per cent out in the thickness of insulation from the conductor. The difference in the permittivities of gas and solid material makes the stress much higher in the gas space, as can be seen by comparing Figs. 4 and 5.

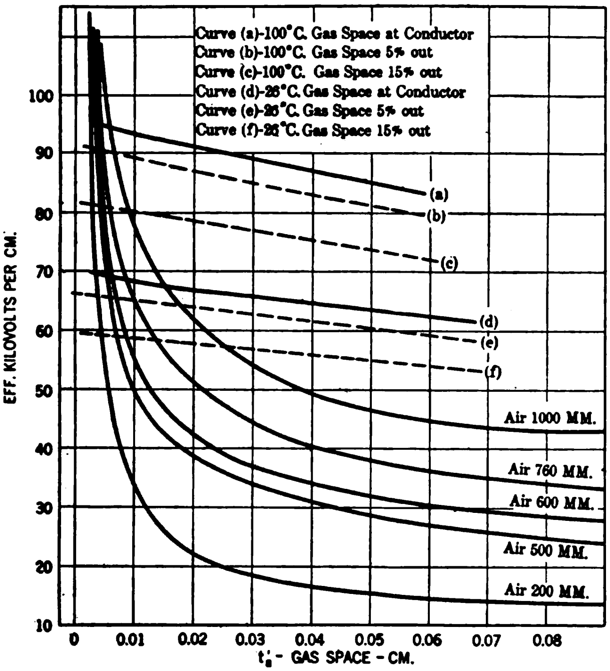

Fig. 5—Cross Curves for Determining Thickness of Gas Space—Sample No. 5 (See Table II)

The strength of air, taken from Table I, is cross plotted in Fig. 5 at various assumed pressures. It is questionable whether the strength of pure air is closely representative of the impure mixture in the gas spaces. However, it serves the purpose of approximation and comparison of the different materials considered. It is interesting to note that according to Thompson the strength of the impure mixture must be higher, not lower, than that of pure air.

Assuming a gas pressure of 650 mm. at 25 deg. cent. and 760 mm. at 100 deg. cent., as previously considered, the corresponding "equivalent pressures" are;

650 mm. at 25 deg. cent.
668 mm. at 100 deg. cent.

With the gas space assumed next to conductor the values of t_a, estimated from Fig. 5 at points where the curves cross are:

0.0068 cm. at 25 deg. cent.
0.0036 cm. at 100 deg. cent.

This decrease of t_a with increase in temperature apparently does not check up with the assumption that the gas pressure is only 760 mm. at 100 deg. cent. for the gas is totally enclosed and must expand or the pressure must increase.

This discrepancy might be accounted for in the following way; t_a measures between adjacent bare surfaces of the slightly loose paper wrappings, or between the under surface of the first wrapping and the conductor. In the general re-adjustment which occurs when the solid material, liquid filler and gas expand the paper wrappings are pressed closer together and the gas allowed to expand in a lateral direction between the paper surfaces, giving greater area but less thickness. This could also account for the disappearance of ionization at higher temperatures that is sometimes met with. The thickness of gas space (t_a) may in these cases be so slight that the stress across it is insufficient to ionize the gas.

Similar curves for sample No. 2 of much smaller cross section are given in Fig. 6. The values of t_a measured from the curves in Figs. 5 and 6 are only slightly different and this is due to the difference in permittivities and starting gradient (g_{max}). The values of t_a are independent of cross section as long as t_a is small compared with the thickness of insulation.

Cable With Large Gas Spaces. Sample No. 6 in Table II was a special length made up with comparatively large gas spaces for test. The first 5 per cent of the paper wrappings were applied loose and crinkled, the remaining wrappings being uniformly firm. The length was then vacuum treated in the usual way but was not left in the compound tank long enough to thoroughly fill it. Compound penetrated the whole cross section but not thoroughly, as was shown by examination after test, the gas spaces in the loose crinkled section being plainly visible when the wrappings were carefully removed.

Curve (*b*) in Fig. 4, extended back to 0 deg. cent. gives a voltage gradient of 12.5 kv. per cm., a dangerously low value. Curves for determining the maximum thickness of gas space are given in Fig. 7. The "equivalent pressures" are:

$$650 \times \frac{296.5}{298} = 647 \text{ mm. at } 23.5 \text{ deg. cent.}$$

$$760 \times \frac{328}{370} = 674 \text{ mm. at } 97 \text{ deg. cent.}$$

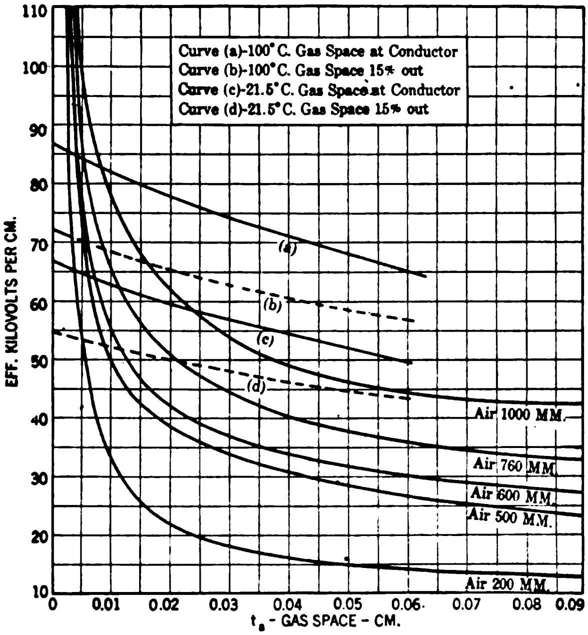

FIG. 6—CROSS CURVES FOR SAMPLE NO. 2 (SEE TABLE II)

With gas spaces assumed next to conductor the values of t_a are:

0.047 cm. at 23.5 deg. cent.
0.023 cm. at 97 deg. cent.

The spaces in this sample are therefore about seven times larger than those in samples Nos. 2 and 5 which are representative of average good cable of this type. It is obvious that large gas spaces are dangerous. All engineers have recognized this. The data given above merely verify a generally accepted view.

It will be noted that the 23.5 deg. cent. curve in Fig. 7 falls below the curve of the dielectric strength of air at 760 mm. This is very good proof that the pressure in the gas spaces is something less than atmospheric at room temperature.

Three-Conductor Paper Cable, Filled with Mineral Hydrocarbon Base Compound. We have had very poor success in attempting to investigate internal ionization and other characteristics of three-conductor cables with actual three-phase voltage. The degree of accuracy in the measurements has not been sufficient to obtain uniform and consistent ionization curves. Our work in this direction agrees with that of F. M. Farmer,[8] in that, as far as can be determined, there is no difference in the actual three-phase losses and those calculated from single-phase measurements. The investigation is being continued and we are hoping for better results later.

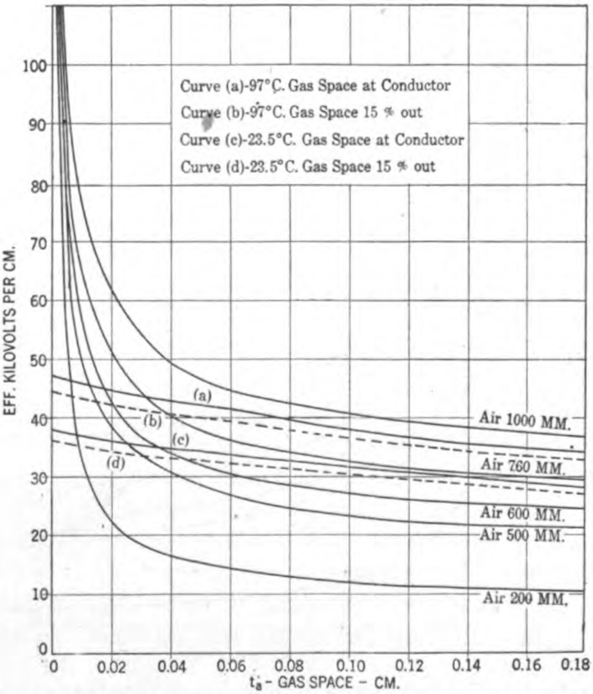

FIG. 7—CROSS CURVES FOR SAMPLE NO. 6 (SEE TABLE II)

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[8] Measurements of Power Loss in Voltage of Three-Conductor High-Tension Cables, by F. M. Farmer, PROC. A. I. E. E., Feb. 1918.

TABLE III.
THREE-CONDUCTOR PAPER CABLE:
FILLED WITH MINERAL HYDRO-CARBON BASE COMPOUND. LEAD SHEATH. STRANDED CONDUCTORS.

Sample No.	Dia. cond. inches	Thick. insul. inches	*Gmax.* kv. per cm. at cond.	Temp. deg. cent.	Freq.	*Kav*	E_S start of ionization	*Gmax.* at start kv. per cm.	Remarks
				NEW SAMPLES—NEVER IN SERVICE					
No. 7	.412	$\frac{9}{32} \times \frac{7}{32}$	1.45*E*	25	60	3.26	15.5	22.48	Three conductors in.
				25	60	3.26	15.5	22.48	Two of conductors withdrawn.
No. 8	.412	$\frac{9}{32} \times \frac{7}{32}$	1.45*E*	22.5	60	3.24	15.0	21.75	Wrappings compact but not very well filled. Loss less than average.
				60	60	3.33	16.0	23.20	
No. 9	.412	$\frac{9}{32} \times \frac{7}{32}$	1.45*E*	48.	60	3.53	16.0	23.20	Average well filled. Loss about average.
				74.	60	3.60	16.4	23.79	
				94.	60	3.61	16.8	24.37	
No. 10	.728	$\frac{7}{32} \times \frac{7}{32}$	1.396*E*	23	60	3.69	17.6	24.57	Well filled. Loss about average.
No. 11	Semi Sector	$\frac{9}{32} \times \frac{5}{32}$	1.121*E*	21	60		20.1	22.53	Assumed as concentric single cond. a = 2.104 cm.
				98	60		22.0	24.70	
				OLD SAMPLES—HAD BEEN IN SERVICE.					
No. 12	.373	$\frac{9}{32} \times \frac{7}{32}$	1.51*E*	24	60	3.23	20.0	30.20	Well filled. Loss a little higher than average.
				51	60	3.40	22.0	33.20	
				77	60	3.44	22.6	34.15	
				101	60	3.53	23.4	35.30	
No. 13	.412	$\frac{9}{32} \times \frac{7}{32}$	1.45*E*	26	60	3.35	20.0	29.00	Well filled. Loss a little higher than average.
				64	60	3.45	22.0	31.90	
				100	60	3.52	24.0	34.80	

The start of ionization between any two conductors cannot be studied with single-phase voltage, but only that between conductor and sheath. This is unfortunate, for in actual three-phase operation the stress is greatest between conductors, whereas with, single-phase voltage the stress is greatest between conductor and sheath, and ionization naturally starts here first, blanketing the results between conductors. A study of the stress between conductor and sheath is instructive, however, and will be given.

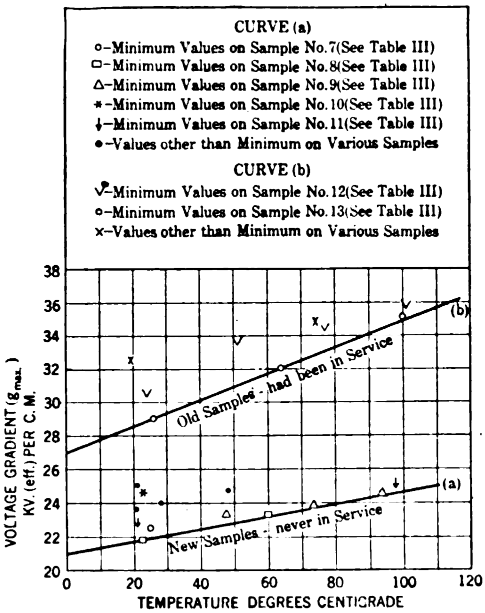

FIG. 8—MAXIMUM GRADIENT BETWEEN CONDUCTOR AND SHEATH (ASSUMING NO SPACE) AT START OF IONIZATION

Three-conductor paper cable filled with mineral hydro-carbon base compound

Calculation of the maximum stress between conductor and sheath (assuming no gas space present) is made by formula (**5**) in the Appendix. In this formula, it is assumed that the proximity of the other two conductors has no effect on g_{max}. The correctness of this assumption is verified by a comparison of the values of g_{max} for new cable in Table III and Fig. 8 with those of single-conductor cable in Fig. 4. A special test on sample No. 7 in Table III gives, perhaps, better verification.

Sample No. 7 was first tested by applying high voltage to all three conductors and grounding the sheath. The voltage at which ionization started (E_s) was found to be 15.5 kv. Two of the conductors were then carefully withdrawn from the sample, strand at a time, and the test repeated. E_s agreed exactly with that found in the first test.

The minimum values of g_{max}. for new samples of three-conductor cable, in Fig. 8 (curve *a*), agree closely with the corresponding values for single-conductor cable, Fig. 4 (curve *a*), and it must be concluded that the conditions, such as thickness of gas space, gas pressure, etc. are the same in both types of cables. This would be expected, since they are made of the same materials and by the same process.

Sample No. 11 has semi-sector shaped conductors. The outer circumference of these conductors are arcs, concentric with the lead sheath. As far as the maximum stress between conductor and sheath is concerned this type can be considered as a single conductor cable and the max. stress calculated in the usual way;

$$g_{max} = \frac{E}{a \log_\epsilon b/a}$$

where, a = the radius to the outer surface of conductor, and b = inner radius of sheath.

Tests on old samples that had been in service, samples No. 12 and 13, gave very interesting results. Curve (*b*) in Fig. 8 shows these to have much higher values of g_{max} when ionization starts. This same permanent increase in E_s has been noted several times in new samples after they had been heated above the melting point of the mineral compound filler. We can only account for it by suggesting some sort of "settling" or re-adjustment of the melted compound and gas spaces in such a way as to make the spaces permanently smaller, at least those nearest the conductor. This probable explanation has previously been offered for the increase of g_{max}. with temperature, although in that case the increase considered was only temporary. The two effects are probably closely related, as will be brought out later.

The study of old samples has been limited and we do not know whether this settling effect is inherent or not. It would hardly be safe to rely upon improvement with aging in every case, and the minimum curve (*a*) in Figs. 4 and 8 should stand as a safer guide. However it is re-assuring to know that the change in ionization with aging is in the right direction.

TABLE IV.

THREE CONDUCTOR PAPER CABLE:

FILLED WITH VEGETABLE HYDRO-CARBON BASE COMPOUND. LEAD SHEATH. STRANDED CONDUCTORS.

Sample No.	Dia. cond. inches	Thick. insul. inches	$G_{max.}$ kv. per cm. at cond.	Temp. deg. cent.	Freq.	K_{av}	E_S start of ionization	$G_{max.}$ at start kv. per cm.	Remarks.
				New Samples—Never in Service.					
No. 14	.528	$\frac{7}{32} \times \frac{7}{32}$	$1.624E$	21	60	3.88	13.5	21.93	Well filled. Losses high.
				58	60	4.43	12.5	20.30	
				100	60	5.40	11.0	17.87	
No. 15	Semi sector	$\frac{6}{32} \times \frac{6}{32}$	$1.243E$	25.5	60		13.0	16.16	Assumed as concentric single cond. a = 2.44 cm. Losses high.
				110.5	60		14.5	18.02	
				Old Samples—Had Been in Service.					
No. 16	.528	$\frac{7}{32} \times \frac{7}{32}$	$1.624E$	29	60	5.03	10.0	16.24	Charred in center. Losses very high.
				55	60	5.52	10.2	16.56	
				75	60	6.10	10.4	16.90	
				111	60	9.37	11.6	18.85	
No. 17	.528	$\frac{7}{32} \times \frac{7}{32}$	$1.624E$	25	60	4.25	8.8	14.30	Undamaged. Poorly filled. Losses high.
				75	60	5.29	10.0	16.24	
				100	60	7.19	10.1	16.40	
No. 18	.528	$\frac{7}{32} \times \frac{7}{32}$	$1.624E$	27	60	4.74	9.5	15.45	Undamaged. Well filled. Losses very high.
				100	60	8.36	10.0	16.20	
No. 19	Semi sector	$\frac{6}{32} \times \frac{6}{32}$	$1.243E$	25.5	60		15.0	18.65	Assumed as single cond. $a = 2.44$ cm. **Losses high.**
				106	60		16.0	19.90	

The relative permittivity (K_{av}) of the insulation between conductor and sheath, as given in Table III, is calculated with a formula for three-conductor cables developed by Alex. Russell. It is given as formula (6) in the Appendix. The calculated K_{av}. agrees favorably with that for single conductor cable.

Three Conductor Paper Cable; Filled with Vegetable Hydrocarbon Base Compound. Before discussing the tests on paper cable filled with vegetable hydrocarbon base compound we wish to point out that our tests were limited to only two lots of this kind and, in particular, that a study of these was made because they had given trouble in operation.

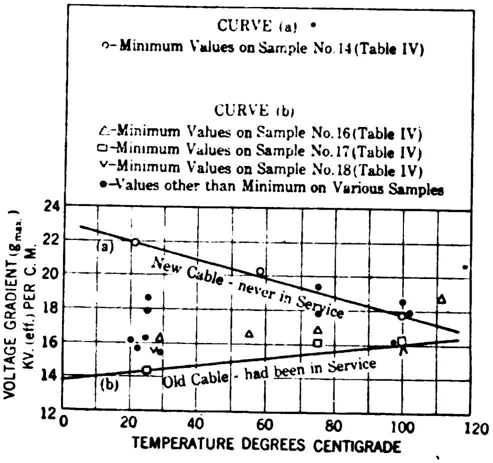

Fig. 9—Maximum Gradient Between Conductor and Sheath (Assuming no Gas Space) at Start of Ionization

Three conductor paper cable—filled with vegetable hydro-carbon base compound

Ionization data are given in Table IV. Samples Nos. 14, 16, 17, and 18 are from the same batch of cable described in the June, 1917, Institute paper previously referred to. Sample No. 14 had never been in service. The others were cut from the lines near points of failure after five years operation. The start of ionization is shown in Fig. 9. It is very low compared with that in Fig. 8, which shows that this lot of cable could not be safely operated at so high a voltage as the other type.

The dielectric losses and temperature coefficient were extremely high, so high in fact, that the temperature rise in operation was appreciable even without load on the cables. This factor alone would limit the voltage rating. With internal ionization and the deterioration it must cause probably included, there is no wonder that the cable gave trouble.

The stress between conductors at which ionization starts could not be determined with single-phase voltage. We cannot say definitely, then, that there was ionization during operation, but judging from the low values of g_{max} between conductor and sheath in Fig. 9 it seems very probable that there was. The paper wrappings between conductors were badly charred in spots. and showed general signs of deterioration. The greater part of this deterioration may have been caused by tangential stresses and leakage over the surfaces of the wrappings as discussed in the previous paper, but ionization must also have had something to do with it. Hochstadter[9] describes ionization in this section of a cable as "glow discharge."

Fig. 9 not only shows a very low voltage gradient for both new and old samples but in addition it shows:

1. that g_{max}. decreases with increase in temperature in the new sample. (curve *a*).
2. that g_{max}. decreases with aging (curve *b*).

It is interesting to compare Figs. 8 and 9. The effects are reversed. The tests so far made on different types of cable insulation have shown that whenever there is an increase or decrease in g_{max}. with temperature in new samples there is a corresponding increase or decrease with aging. This would tend to show that the two effects, whatever their cause are closely related.

Formula (3) in the Appendix does not apply to three-conductor cable and there is no way of approximating the thickness of gas space t_a. It is apparent, however, that t_a is greater than that found for paper cable filled with mineral hydrocarbon compound, although the higher value of permittivity is also a determining factor in making g_{max}. lower.

Samples No. 15 and 19 in Table IV are from a different lot of cable than those dealt with above. The curves for these samples are in Fig. 10. Their characteristics are not the same as those of the first lot, more nearly resembling those in Fig. 8 although the values of $g_{max.}$ are considerably lower.

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[9] "Three-Core Cable," by M. Hochstadter, *Electrotechische Zeitschrift*, Heft 47, 1915.

This lot of cable did not give as much trouble in operation as the first, even though the dielectric losses were just as high. Allowing for possible differences in the operating conditions it would still seem that the lesser trouble experienced with this lot was due to its more favorable ionization characteristics, that is, improvement with aging.

Varnished Cambric Tape; Wrapped Half-lap on Conductors of Round Cross Section. The ionization data for 0.010 in. black varnished cambric tape, wrapped half-lap on round conductors is given in Table V.

Two samples of lead-sheathed single-conductor cable (samples No. 20 and 21) are also given in this table. Sample No. 20 is varnished cambric cable and sample No. 21 varnished paper. They both were well filled with cable compound, this being accomplished by running the tape through the compound.

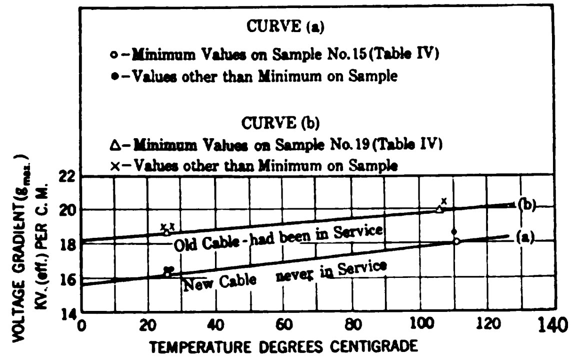

Fig. 10—Maximum Gradient between Conductor and Sheath (assuming no gas space) at Start of Ionization

Three conductor paper cable—filled with vegetable hydro-carbon base compound

The other samples under the heading, "Filled as Tapings were Applied." were wrapped on brass tubes, wet varnish being brushed on as the tapings were applied. These were first tested without heat treatment, and then after baking at 100 deg. cent., as designated in the table. Metal foil tape was wrapped over the surface and bound down tightly with adhesive tape.

The minimum curve of $g_{max.}$ *vs.* temperature for the filled samples is in Fig. 11 and the cross curves of stress in gas space

TABLE V.
.010'' VARNISHED CAMBRIC TAPE:
WRAPPED HALF-LAP ON CONDUCTORS OF
ROUND CROSS SECTION.

Sample No.	Type of conductor	Dia. cond. inches	Thick. insul. inches.	g_{max}. kv cm. at cond.	Temp. deg. cent.	Freq.	K_{av}	E_s start of ionization	g_{max}. at start kv. cm.	Remarks.
					FILLED AS TAPINGS WERE APPLIED.					
No. 20	stranded	.412	9/32	$2.218E$	25	60	4.07	8.5	18.85	Black varnished cambric cable. Lead sheath.
					50	60	4.55	8.4	18.64	
					75	60	5.20	none		
No. 21	stranded	.412	9/32	$2.218E$	35	60	3.53	8.3	18.41	Black varnished paper cable. Lead sheath.
					75	60	4.15	8.5	18.85	
					100	60	4.76	10.1	22.40	
					125	60	5.08	10.6	23.50	
No. 22	smooth	.538	.331	$1.82E$	23.5	60	4.20	10.2	18.56	Black varnished cambric wraped on brass tubes. Tin foil wrapped tightly outside.
					58	60	4.80	10.1	18.39	
					104	60	5.95	11.2	20.40	
					(a) 20.5	60	4.01	10.0	18.20	
No. 23	smooth	.528	.0975	$4.74E$	23.5	60	4.05	4.0	18.95	Same as Sample No. 22.
					58	60	4.55	4.2	19.90	
					103	60	6.20	4.5	21.30	
					(a) 21	60	3.80	3.8	18.02	
No. 24	smooth	1.527	.277	$1.665E$	22.5	60	4.46	11.5	19.16	Same as Sample No. 22.
					57.5	60	4.72	11.8	19.66	
					101	60	5.60	12.9	21.50	
					(a) 20	60	4.17	11.1	18.50	
No. 25	smooth	1.533	.0845	$4.92E$	23.5	60	4.00	3.8	18.70	Same as Sample No. 22.
					56.5	60	4.51	4.0	19.68	
					103.	60	6.40	4.3	21.15	
					(a) 21	60	3.70	3.7	18.21	

TABLE V.—(*Continued*)
.010″ VARNISHED CAMBRIC TAPE WRAPPED HALF-LAP ON CONDUCTORS OF ROUN CROSS SECTION.

Sample No.	Type of conductor	Dia. cond. inches.	Thick. insul. inches.	g_{max} kv. cm. at cond.	Temp. deg. cent.	Freq.	K_{av}	E_s Start of ionization	g_{max} at start kv. cm.	Remarks.
					(b) No Filling Taping Applied Dry.					
No. 26	smooth	.530	.294	1.988E	23.5	60	4.16	9.0	17.90	Black varnished cambric wrapped on brass tubes. Tin foil wrapped tightly outside.
					62	60	4.68	10.0	19.88	
					102.5	60	5.15	11.1	22.07	
					(c) 23.5	60	4.08	8.8	17.50	
					23.5	25	4.08	9.1	18.10	
					62.	25	4.71	10.5	20.87	
					103.	25	5.43	11.1	22.07	
					(c) 23.	25	4.08	8.8	17.50	
No. 27	smooth	.534	.133	3.63E	19.5	60	4.87	4.6	16.70	Same as Sample No. 26.
					61.5	60	5.62	5.2	18.90	
					101.	60	5.96	5.5	19.95	
					(c)23.	60	4.79	4.6	16.70	
					23.5	25	5.00	4.6	16.70	
					62.5	25	5.96	5.2	18.90	
					102.	25	6.21	5.6	20.33	
					(c) 22.5	25	4.82	4.7	17.05	
No. 28	smooth	1.529	.292	1.592E	23.5	60	3.90	11.0	17.50	Same as Sample No. 26.
					59.5	60	4.35	12.2	19.40	
					101.5	60	4.76	13.0	20.70	
					(c) 23.5	60	3.94	11.0	17.50	
					19.5	25	4.10	11.4	18.15	
					61.5	25	4.50	12.2	19.40	
					102.5	25	4.95	12.8	20.40	
					(c) 23.	25	3.98	11.0	17.50	
No. 29	smooth	1.510	.0925	4.525E	21	60	3.75	4.0	18.10	Same as Sample No. 26
					57	60	4.35	4.2	19.00	
					102.5	60	4.86	4.7	21.27	
					(c) 24	60	3.88	3.9	17.64	
					24	25	4.00	4.2	19.00	
					62	25	4.99	4.2	19.00	
					102.5	25	5.22	4.7	21.27	
					(c) 23.	25	3.90	4.0	18.10	

(a) Note: These measurements were taken after samples had been baked in oven 24 hrs. at 50 deg. cent. and 5 hrs. at 100 deg. cent.
(b) All of the samples under this heading were baked 72 hrs. at 50 deg. cent. and 24 hrs. at 100 deg. cent. before testing.
(c) Baked an additional 24 hrs. at 50 deg. cent. and 5 hrs. at 100 deg. cent.

and strength of air in Figs. 12 and 13. The stress in the gas spaces (g_a) was calculated by determining values of E_s from the minimum curve in Fig. 11 and using an average low value of K_{ar} from Table V.

The thickness of gas space (t_a) measured from the cross curves in Figs. 12 and 13 is therefore the maximum expected in this type of insulation.

Assuming the gas pressure as 760 mm. at both 25 deg. cent. and 100 deg. cent the "equivalent pressures" are:

760 mm. at 25 deg. cent.
607 mm. at 100 deg. cent.

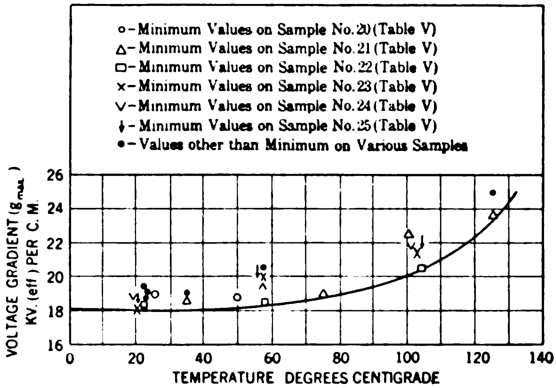

FIG. 11—MAXIMUM GRADIENT BETWEEN CONDUCTOR AND OUTER METALLIC WRAPPING (ASSUMING NO GAS SPACE) AT START OF IONIZATION

Varnished cambric tape—wrapped half lap on conductors of round cross section—filled as tapings were applied

With the gas space assumed next to conductor the values of t_a are:

0.008 cm. at 25 deg. cent.
0.003 cm. at 100 deg. cent.

The thickness of gas space given above is within the same order as that for paper cables filled with mineral hydrocarbon compound. The values of $g_{max.}$ however, are lower because of the higher permittivity of varnished cambric.

Ionization data are given under a separate heading in Table V for samples of 0.010-in. black varnished cambric tape wrapped on brass tubes without a filler, that is, no wet varnish brushings were applied. These samples were thoroughly dried out in an oven just before testing to make sure that no excess moisture was present. The minimum curve of g_{max}. is in Fig. 14. It is surprising to note that it is only slightly lower than the corresponding curve in Fig. 11. Larger gas spaces at the edges of the overlapped wrappings would naturally be expected.

The values of t_a corresponding to those given for the filled samples are:

0.011 cm. at 25 deg. cent.
0.0035 cm. at 100 deg. cent.

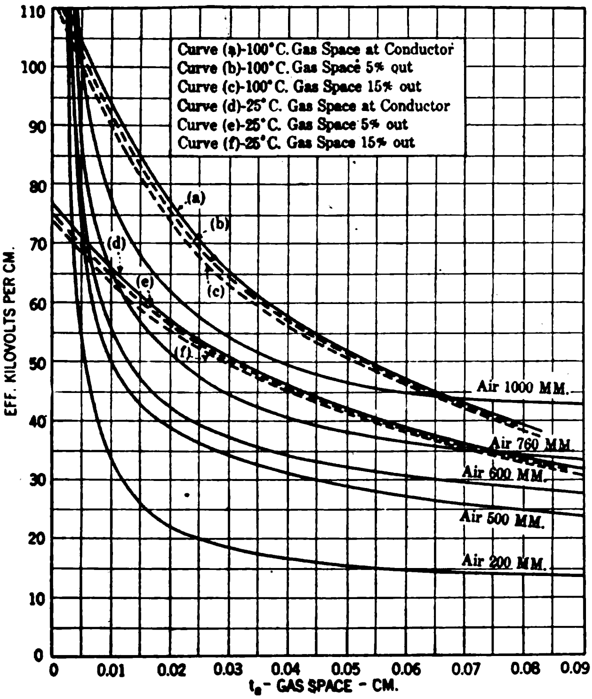

FIG. 12—CROSS CURVES FOR SAMPLE NO. 25 (SEE TABLE V)

These values were taken from curves similar to the curves in Figs 12 and 13.

The actual maximum thickness of the space at the edge of the wrappings must be greater than estimated above, as the wrappings were each 0.010 in. (0.0254 cm.) thick. We believe the discrepancy can be accounted for in the following way:

In calculating g_a it is assumed that the dielectric lines of flux are uniformly straight radial lines. In passing through the thin gas spaces of comparatively large area, usually met with between the surfaces of wrappings, they doubtless are, at least towards the center of the space where t_a is a maximum and ionization first occurs. But, the space at the edge of the wrappings is nothing but a narrow thread-like spiral and the stress lines are partly shunted around it through the solid material of higher permittivity. Consequently, either the ordinary spaces between surfaces are ionized first, in which case the calculations are correct, or the narrow edge spaces are actually ionized at a lower value of g_a than that wrongly estimated.

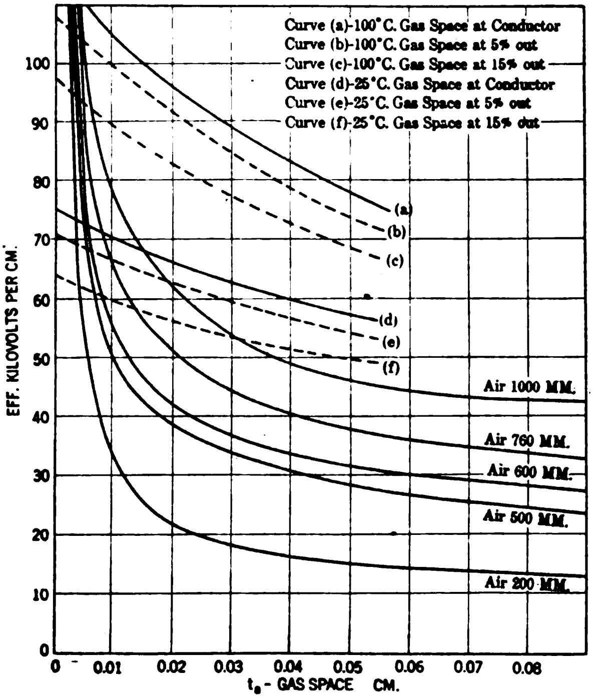

FIG. 13—CROSS CURVES FOR SAMPLE NO. 22 (TABLE V)

This same line of reasoning would apply to unfilled wrinkles or creases in wrappings, and also to the small capillary passages which form as the filler is dried out.

Flexible Mica-Paper Tape; Wrapped Half-lap on Conductors of Round Cross Section. Pasted flexible mica-paper has characteristics somewhat different from the usual run of flexible organic materials. This difference is due to the interruptions, or barrier effect, of the laminated inorganic mica flakes. Pasted mica-paper can be better understood if it is considered as having the combined characteristics of mica flakes and varnished sheet material such as paper or cambric.

Pure mica is more permanently stable than any other insulating material. Its electrical characteristics, such as dielectric strength, permittivity and energy loss are almost independent of length of voltage application and temperature between 0 deg. and 300 deg. cent.

The organic paper backing and sticker introduce between the flakes of mica those characteristics usually met with in organic solid materials, that is, comparatively high temperature coefficient, and deterioration and porosity with aging.

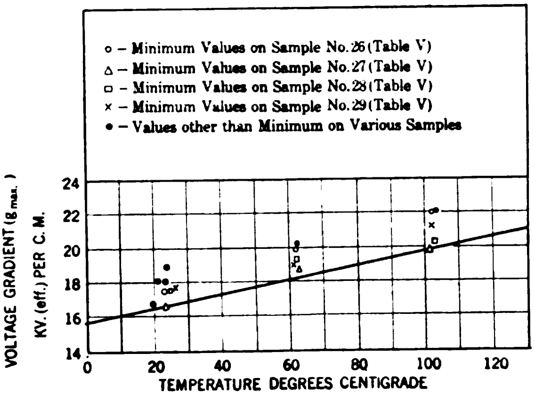

Fig. 14—Maximum Gradient at Start of Ionization (assuming no gas space)

Unfilled varnished cambric tape wrapped half lap on conductors of round cross section

The a-c. leakage path (also porosity and deterioration when present) follows the path of the organic components, zig-zagging in and out around the mica flakes and wrappings searching out the shortest and easiest path through the thickness.

When mica-paper is wrapped on conductors of rectangular cross section extreme care must be taken to prevent the insulation from loosening up and bulging away from the sides. The natural spring of mica flakes and softening of the sticker under heat treatment tend to cause this bulging. On round cross sections there is no tendency to bulge and, hence, one of

TABLE VI.
FLEXIBLE MICA PAPER TAPE:
WRAPPED HALF-LAP WITH STICKING VARNISH ON CONDUCTORS OF ROUND CROSS SECTION. STICKER DRIED BY HEAT CURING.

Sample No.	Dia. Cond. inches	Thick. insul. inches	g_{max} kv. per cm. at cond.	Temp. deg. cent.	Freq.	*Kav*	E_n start of ionization	g_{max} at start kv. per cm.	Remarks.
					Fresh Samples—Cured but not Aged.				
No. 30	.536	.07075	6.27*E*	26.	60	2.98	4.2	26.30	Metal foil tape wrapped over outer surface and tightly bound down with adhesive tape.
				65.	60	4.11	4.0	25.10	
				105	60	5.46	4.1	25.70	
				25	25	3.10	4.2	26.30	
				67	25	5.20	4.0	25.10	
				102	25	6.40	4.0	25.10	
No. 31	.535	.2512	2.22*E*	26	60	3.05	11.7	26.00	
				68	60	4.16	11.4	25.30	
				105	60	5.70	11.4	25.30	
				26	25	3.28	11.4	25.30	
				67	25	5.16	11.6	25.75	
				104	25	6.51	11.8	26.20	
No. 32	1.51	.073	5.66*E*	26	60	3.15	4.7	26.60	
				64	60	4.09	4.25	24.05	
				105	60	5.99	4.3	24.35	
				25	25	3.36	4.7	26.60	
				68	25	5.22	4.3	24.35	
				103	25	6.77	4.5	25.50	
No. 33	1.51	.118	3.58*E*	22	60	3.22	7.0	25.06	
				61	60	4.31	6.9	24.71	
No. 34	1.53	.211	2.155*E*	25	60	3.02	12.2	26.30	
				106	60	5.38	12.0	25.90	
				28	25	3.25	13.0	28.00	
				65	25	5.26	12.0	25.90	
				103	25	6.65	12.0	25.90	
					Old Samples—Aged in Oven at High Temp.				
No. 35	1.51	.120	3.53*E*	24	60	2.95	6.0	21.18	Baked 24 hr at 50 deg. cent. " 24 hr at 75 deg. cent. " and 84 hr. at 100 deg. cent.
				62	60	3.20	6.1	21.53	
				103	60	3.99	6.0	21.18	
No. 36	1.51	.116	3.66*E*	25	60	2.87	5.7	20.87	Same baking as sample No. 35 and in addition 84 hr at 150 deg. cent.
				101	60	3.10	5.6	20.50	
				152	60	3.51	5.4	19.77	
No. 37	1.51	.118	3.58*E*	28	60	2.65	5.8	20.75	Same baking as sample No. 36 and in addition 290 hr. at 200 deg. cent.
				106	60	2.85	5.6	20.05	
				200	60	3.12	5.5	19.70	

the most troublesome characteristics of pasted mica is eliminated when used in this way.

Ionization data for representative samples of mica paper insulation are given in Table VI and the minimum curves of g_{max} in Fig. 15. The wrappings were compactly applied half-lap with sticking varnish on round brass tubes, and heat cured to drive out the solvent.

The minimum curve of g_{max}. for fresh material in Fig. 15 is higher than that for any other material so far considered.

Samples No. 35, 36 and 37 in Table VI were aged in an oven respectively at 100 deg. cent., 150 deg. cent. and 200 deg. cent. They are minimum representatives of a number of samples aged for different periods of time at the above temperatures.

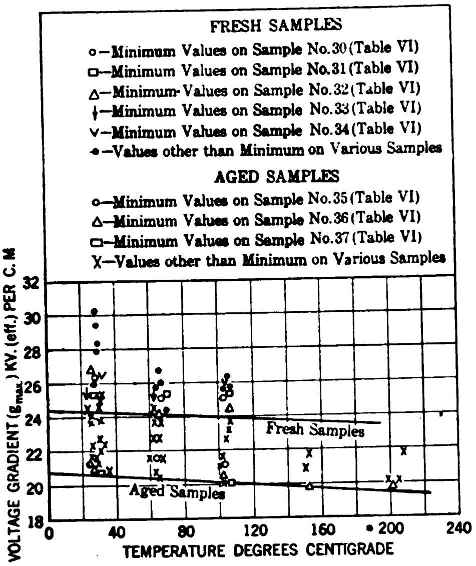

Fig. 15—Maximum Gradient at Start of Ionization (assuming no gas space)

Flexible mica-paper-wrapped half-lap on conductors of round cross section.

Baking at high temperature volatilizes a considerable part of the organic components and renders the insulation brittle and extremely porous. The degree of porosity was shown clearly in two ways:

1. The additional dielectric loss caused by ionization was much greater than the corresponding loss in fresh samples. This was shown by comparison of ionization curves similar to that in Fig. 1.

2. When aged samples were exposed to moisture the absorption by the capillary passages of the porous organic components increased the dielectric loss enormously. In fact it was almost impossible to reach voltage E_s without breakdown when the samples were well saturated.

The minimum curve of g_{max} for aged samples in Fig. 15 indicates that aging enlarges the gas spaces, as would be expected.

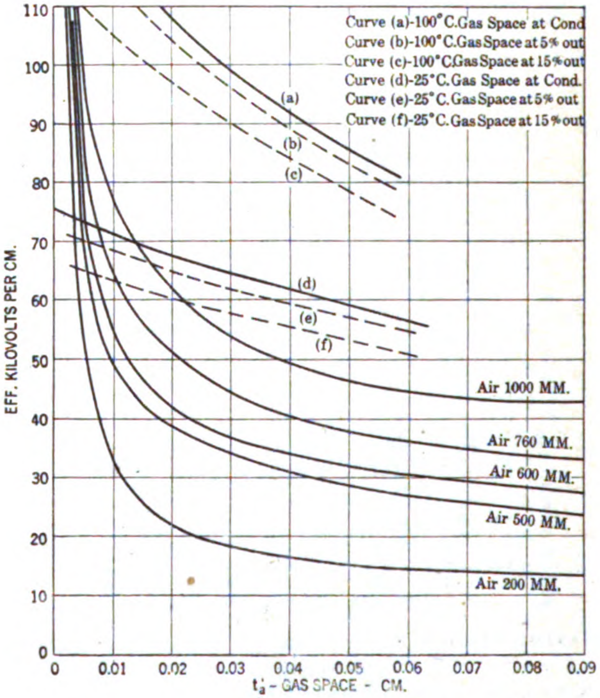

FIG. 16—CROSS CURVES FOR SAMPLE NO. 31 (SEE TABLE VI)

The cross curves for determining the maximum thickness of gas space for fresh samples are in Fig. 16. The curves of g_a were calculated by taking values of E_s from the minimum curve in Fig. 15 and minimum average values of K_{av}. The maximum ratio of b/a (sample No. 31) is considered.

Assuming the gas pressure as 760 mm. both at 25 deg. cent. and 100 deg. cent. the "equivalent pressures" are:

760 mm. at 25 deg. cent.
607 mm. at 100 deg. cent.

From the cross curves the values of t_a assumed next to conductor are:

0.0075 cm. at 25 deg. cent.
0.0025 cm. at 100 deg. cent.

The cross curves for sample No. 37, a representative aged sample, are shown in Fig. 17. Assuming a constant gas pressure of 760 mm. the "equivalent pressures" are:

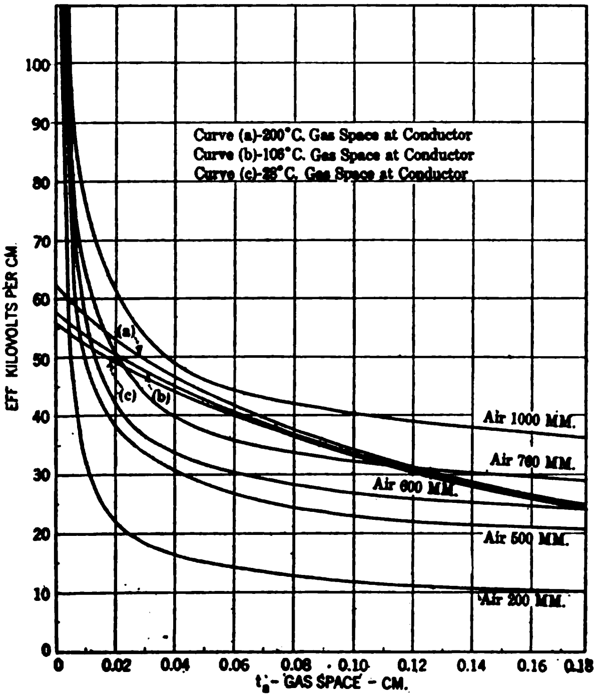

FIG. 17—CROSS CURVES FOR SAMPLE NO. 37 (SEE TABLE VI)

$$760 \times \frac{298}{304} = 752 \text{ mm. at 28 deg. cent.}$$

$$760 \times \frac{298}{379} = 598 \text{ mm. at 106 deg. cent.}$$

$$760 \times \frac{298}{473} = 479 \text{ mm. at 200 deg. cent.}$$

From the cross curves the values of t_a assumed next to conductor are.

0.023 cm. at 28 deg. cent.
0.012 cm. at 106 deg. cent.
0.0065 cm. at 200 deg. cent.

Aging has enlarged the gas spaces appreciably.

INSULATION WRAPPED ON CONDUCTORS OF RECTANGULAR CROSS SECTION

The results given thus far in the paper have been fairly consistent because samples of round cross section only have been considered. The way the values of $g_{max.}$ in Figs. 4, 8, 9, 10, 11, 14 and 15 have bunched has made it possible to assign definite minimum curves of $g_{max.}$ for the different materials, and from these determine a safe working stress. This has been possible because of the fact that the thickness of gas space (t_a) has been so small that $g_{max.}$ has been practically independent of both conductor diameter and thickness of insulation. It is dependent only upon the kind of material used, method of application, treatment and aging.

An attempt to give minimum curves of the stress at which ionization starts (g_s, assuming no gas space) for samples of rectangular cross section leads only to misrepresentation and confusion. The tendency for the insulation to bulge away from the straight sides of the conductors, and therefore the maximum thickness of gas space, is not only more vitally dependent upon those factors associated with samples of round cross section, but also upon the dimensions of the conductor and thickness of insulation. Then too, we are approaching values of t_a that are appreciable when compared with the thickness of insulation and for this reason g_s varies with thickness.

The most satisfactory way to deal with rectangular cross sections, such as armature coils, is to measure the voltage at which ionization starts in each individual case. The value of E_s will indicate whether the particular type of coil can be safely operated at its rated voltage or not. Also, the thickness of gas space determined from these measurements will indicate the degree of puffing or bulging by comparison with a similar sample of round cross section, which can be considered as a standard representing the best possible attainment, that is, as having the least values of t_a for the given conditions.

Before dealing with actual tests on coils consideration will again be given to round cross sections to illustrate, by indirection, a peculiar characteristic which has been met with only in rectangular cross sections.

Referring to Fig. 12, as representative of round cross sections, the 25 deg. cent. curve of stress in gas space at conductor crosses the 760 mm. strength of air curve at both 0.009 cm. and 0.075 cm. It is evident that for any thickness smaller than 0.009 cm. or larger than 0.075 cm. there will be no ionization at the impressed voltage of 3.64 kv.

Now, the actual maximum thickness of gas space is selected as 0.009 cm. instead of 0.075 cm. for the following reasons:

a. For any thickness between the above limits, ionization would have started at a lower value of E_s.

b. If a gas space between surfaces is considered as having 0.075 cm. as its maximum thickness, then from the nature of its shape the thickness must vary from zero at its edges to 0.075 cm. in the center, consequently somewhere through the gas space there will be a critical thickness, which we will call t_c, at which ionization will start at a minimum E_s lower than 3.64 kv. It would have the effect of lowering the 25 deg. cent. stress curve so that it would be just tangent to the 760-mm. curve at t_c, (in this case t_c is approximately 0.035 cm.)

This critical thickness has not been experienced in round cross sections because the maximum thickness of gas space has always been something less than this. It is, however, experienced quite often in coils and leads to an interesting and important conclusion concerning them, in that, any degree of puffing or bulging beyond t_c does not lower the voltage E_s at which ionization starts.

Ionization data for a few representative coils are given in Table VII. Sample No. 38 is one of a number made up and tested under conditions whereby the gas spaces would be reduced to the smallest possible size. The insulation was applied as compactly as possible and it was tightly clamped in moulds during the treating process and throughout test. Metal foil was wrapped over the outer surface and tightly bound down, serving as one electrode.

The voltage stress (g_s) at which ionization starts is found merely by dividing E_s by the thickness of insulation. This is a closer approximation than would at first appear, as the bulging is always a maximum at the center of the widest straight side where the lines of stress are practically parallel. Divergent

TABLE VII.
FLEXIBLE MICA-PAPER TAPE:
WRAPPED HALF-LAP WITH STICKING VARNISH ON CONDUCTORS OF RECTANGULAR CROSS SECTION. CURED DURING APPLICATION.

Sample No.	Cond. inches	Thick. insul. inches	g kv. per cm.	Temp. deg. cent.	Freq.	K_{av}	E_S start of ionization	g_S at start kv. per cm.	Remarks.
				Tested in Mechanical Clamps.					
No. 38	1/2 × 3	.0960	4.10E	24.7	60	4.00	5.6	22.97	Insulation compactly applied and well cured while clamped. No aging.
				100	60	5.20	5.5	22.55	
				151	60	6.20	5.6	22.97	
		.0930	4.23E	25	60	3.10	5.5	23.27	Aged in an oven while clamped for 170 hr. at 200 deg. cent.
				100	60	3.30	5.3	22.42	
				198	60	3.60	5.6	23.70	
				Compact Coils Tested Without Clamps					
No. 39	1/2 × 3	.112	3.51E	25	60	3.80	5.1	17.91	Insulation applied and cured compactly. Good grade. No aging.
				60	60	4.40	5.1	17.91	
				102	60	4.90	5.1	17.91	
No. 40	1/2 × 3	.322	1.22E	26	60	3.80	12.4	15.13	Same as Sample No. 39.
				60	60	4.40	12.3	15.01	
				101	60	4.90	12.2	14.88	
				Tested Without Clamps—Not Very Compact.					
No. 41	1/2 × 3	.110	3.58E	25	60	3.87	4.5	16.11	Insulation bulged but not badly.
				61	60	4.40	4.5	16.11	
				100	60	4.90	4.4	15.75	
No. 42	1/2 × 3	.322	1.22E	25	60	3.80	10.0	12.20	Same as Sample No. 41.
				60	60	4.40	10.0	12.20	
				102	60	4.90	10.0	12.20	
				Coil Badly Puffed—no Clamps.					
No. 43	1/2 × 3	.328	1.196E	25	60	3.85	10.0	11.96	Insulation caused to bulge badly by sudden application of high temperature.
				61	60	4.30	8.4	10.05	
				100	60	4.75	7.2	8.61	

stress lines occur only at the corners and the insulation is very compact here.

The values of g_s are comparable with corresponding values of $g_{max.}$ for mica samples of round cross sections in Table VI, showing how compact this coil was. The clamps prevented bulging when the coil was aged at 200 deg. cent. and consequently there was not much change in g_s.

The working stress of coils varies over a wider range than for other insulation designs. It is usually somewhere between 20 and 37 volts per mil (7.87 and 14. 57 kv. per cm.) depending upon such factors as mechanical stress and abrasion, working temperature, etc. Ionization started in sample No. 38 at 57 volts per mil (22.5 kv. per cm.) If it were possible to actually operate this coil under the same favorable conditions it is evident that it could be safely stressed much higher than the very highest stress used in ordinary operation.

The stress in gas spaces of assumed thicknesses cannot be calculated unless the effective permittivity (K_{av}) is known. K_{av} cannot be determined from measurements on rectangular cross sections because the dielectric field is not symmetrical. The best that can be done is to approximate g_a by selecting values of K_{av} by judgment, using those values found in round cross sections of similar material as a guide. The results are fairly good but K_{av} varies too much in different batches, treating processes, etc., to make this method more than a fair approximation. Whenever the maximum thickness of gas space is equal to or greater than the critical thickness (t_c), K_{av} can be found directly in the following way:

For a first trial a value of K_{av} is selected as above to correspond as closely as possible to the true value. The curve g_a vs. t_a is calculated and compared with the strength of air curve of the right "equivalent pressure." If K_{av} is properly chosen it will be almost tangent to the strength of air curve. Another curve is drawn in parallel to the first and exactly tangent. The point of tangency will indicate the value of t_c. Knowing this, the true value of K_{av} and the correct curve of g_a vs. t_a can be calculated.

The cross curves for sample No. 38 are in Fig. 18. The g_a vs. t_a curves all cross their corresponding "equivalent pressure" curves, showing that the gas space is less than t_c. In selecting the values of K_{av} weight was given to the following factors:

(a) K_{av} should be higher than for the round cross sections in Table VI as the insulation was applied differently in the two cases. For the round cross sections all of the insulation was wrapped on with wet sticker between wrappings. The whole was then cured at high temperatures until the varnish was well dried out. The escaping gases consequently caused porosity, and added to this, there must have been many very small spaces formed between surfaces from shrinkage of the sticker as it dried out. The percentage of solid material was reduced and thereby the effective permittivity. For the rectangular cross sections, the layers were carefully cured and moulded as applied, largely closing up capillary passages and other small spaces generally distributed through the thickness and increasing the effective permittivity.

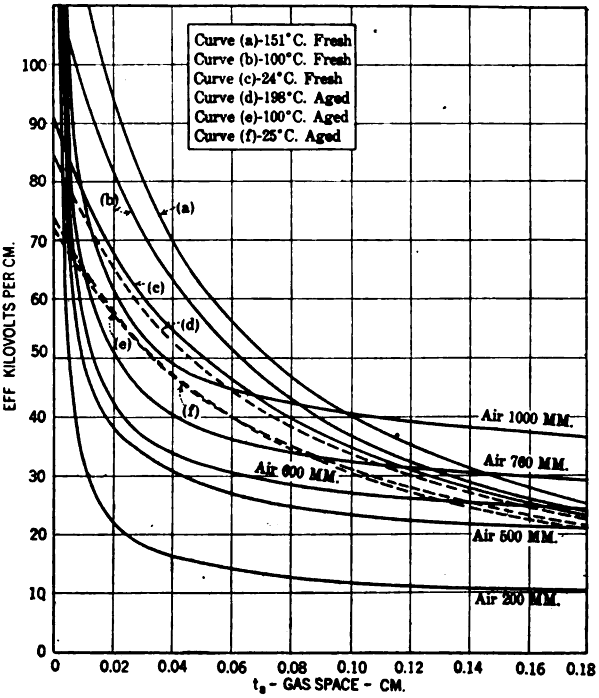

FIG. 18—CROSS CURVES FOR SAMPLE NO. 38 (TABLE VII)

(b) Energy loss measurements give the total capacity of the sample and show how this capacity varies with temperature. The actual permittivity should, of course, vary exactly the same. There remains, then, only to select an arbitrary value of K_{av} for one temperature.

(c) In samples of the same kind, the insulation can be caused to bulge, by sudden application of high temperature until t_a is equal to or greater than the critical thickness at room temperature. Tangent curves as previously discussed will give K_{av} direct. This K_{av} should, however, be a little less than that for sample No. 38, (see sample Nos. 41 and 42) which was tightly clamped and more compact.

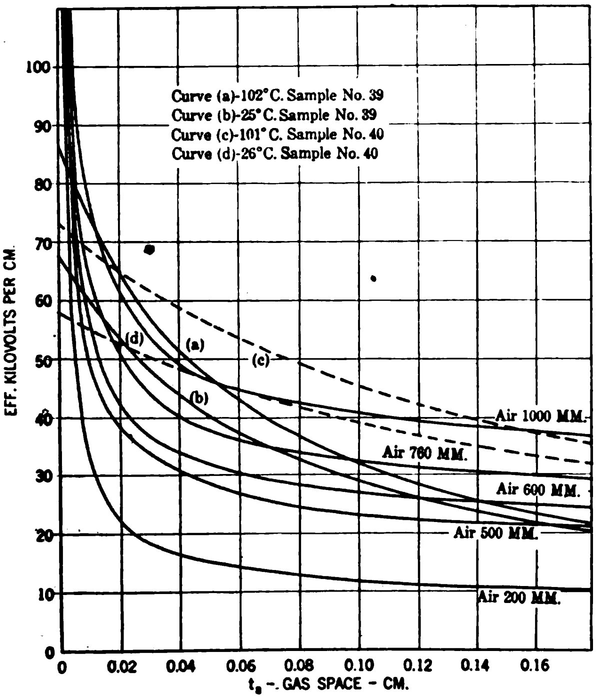

FIG. 19—CROSS CURVES FOR SAMPLES NOS. 39 AND 40 (SEE TABLE VII)

Using "equivalent pressures" in the usual way, the values of t_a in Fig. 18 are:

FRESH	AGED
0.005 cm. at 24 deg. cent.	0.010 cm. at 25 deg. cent.
0.003 cm. at 100 deg. cent.	0.007 cm. at 100 deg. cent.
0.0025 cm. at 150 deg. cent.	0.0045 cm. at 198 deg. cent.

These thicknesses are even smaller than those in samples of round cross section. We believe this is accounted for partly by the tight clamping and partly by the more compact nature of the material, that is, presence of more organic sticker.

Samples No. 39 and 40 are exactly similar to No. 38 but were not tested in clamps. They are representative of good grade compactly made coils in which every reasonable care has been taken to reduce the gas spaces to a minimum. No. 39 has 0.2845 cm. (0.112 in.) thickness of insulation and ionization starts at a stress of 17.91 kv. per cm. (45.5 volts per mil) No. 40 has 0.818 cm. (0.322 in.) thickness and ionization starts at only 15.0 kv. per cm. (38.2 volts per mil). In other words, the thicker the insulation the less the stress it will stand. This characteristic is inherent in rectangular cross sections and is due to the gas spaces being appreciable compared with thickness of insulation. It is evident that there will be no ionization in sample No. 39 at the very highest stress ordinarily used in operation, while No. 40 would be limited to a working stress of about 14.17 kv. per cm. (36 volts per mil), which is a little

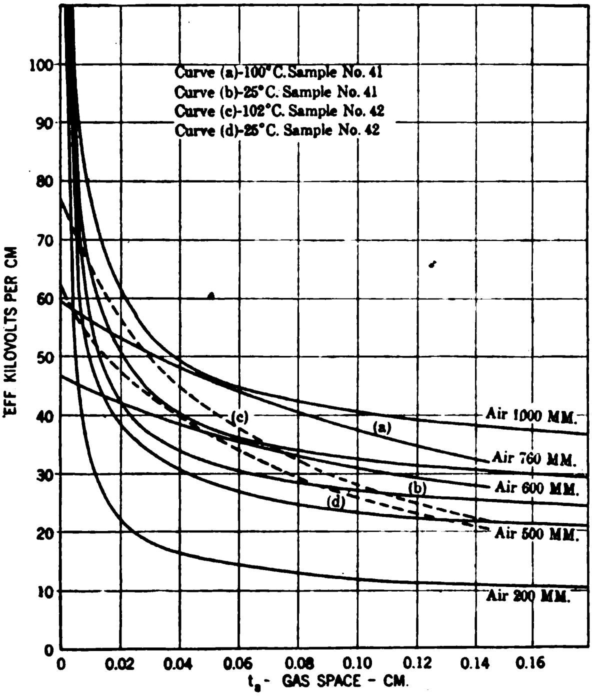

FIG. 20—CROSS CURVES FOR SAMPLES NOS. 41 AND 42 (TABLE VII)

less than the maximum limit but actually higher than would be required in operation for so great a thickness. A working stress of 36 volts per mil is based on the assumption that the operating conditions, such as maximum temperatures, etc., will be such that the gas spaces will not be enlarged with aging. The cross curves for No. 39 and 40 are in Fig. 19. The values of t_a are:

SAMPLE NO. 39	SAMPLE NO. 40.
0.015 cm. at 25 deg. cent.	0.018 cm. at 26 deg. cent.
0.005 cm. at 102 deg. cent.	0.0065 cm. at 100 deg. cent.

Samples No. 41 and 42 in Table VII are representative of poor grade coils in which the insulation has bulged out, not extremely so, but enough to be visible. Ionization starts at 16 kv. per cm. (40.7 volts per mil), in No. 41 and 12.2 kv. per cm. (31 volts per mil) in No. 42. This points to the conclusion that the higher the voltage rating of a coil, in other words, the greater the thickness of insulation, the more carefully bulging must be guarded against.

The cross curves in Fig. 20 indicate that at room temperature the maximum gas space is equal to or greater than the critical in both No. 41 and 42, for the g_a vs. t_a curves are tangent to the 760 mm. curves. At 60 and 100 deg. cent. the stress curves cross their "equivalent pressure" curves, which tends to show that at room temperature the maximum and critical gas spaces must have been almost the same, otherwise expansion of the insulation could not have closed the spaces up so effectively at higher temperatures. The thickness of gas spaces in Fig. 20 are:

SAMPLE NO. 41.	SAMPLE NO. 42.
0.035 cm. at 25 deg. cent. (critical)	.06 cm. at 25 deg. cent. (critical)
0.007 cm. at 100 deg cent.	.011 cm. at 102 deg. cent.

This apparent reduction in thickness of gas space with increase in temperature is based entirely on the assumption adhered to throughout the paper of atmospheric pressure at the higher temperatures as well as at room temperature. If the pressure is assumed to increase with temperature it is possible to even get an increase in gas space with temperature. We are confident that the assumption of atmospheric pressure at room temperature is correct but are free to confess that we have sometimes doubted the assumed pressure at higher temperatures because of the unreasonable decrease in gas space. Every bit of evidence we have, with the exception of this one contradiction, has forced us to the conclusion of atmospheric pressure at all temperatures. When the temperature is raised too rapidly there is certainly an increase in gas space, due to internal gas pressure, as bulging is plainly visible. In all of our tests, however, the temperature is brought up very slowly and everything allowed to stabilize before readings are taken.

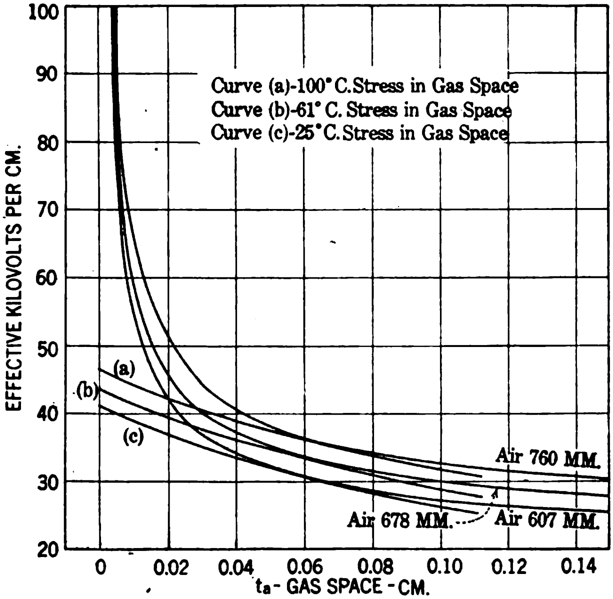

FIG. 21—TANGENT CURVES FOR SAMPLE NO. 43 (TABLE VII) SHOWING CRITICAL THICKNESS OF GAS SPACE

For this reason, it is possible that the pressure is held at atmospheric by the small capillary orifices.

The data on sample No. 43, a badly puffed coil, prove beyond any doubt that the gas pressure was practically atmospheric for all temperatures. Whether the internal gas pressure of a coil in this condition is representative of the more compact coils is problematical. The g_a vs. t_a curves in Fig. 21 are all tangent to their respective "equivalent pressure" curves and the permittivity K_{av}, found in this way is so nearly that which would be expected that there is little doubt of the assumed pressures being correct. Apparently the maximum thickness of gas space is considerably greater than the critical, at least at room temperature. The values of t_c are:

0.063 cm. at 25 deg. cent.
0.062 cm. at 61 deg. cent.
0.061 cm. at 100 deg. cent.

No. 43 had an insulation thickness of 0.833 cm. (0.328 in.) At 100 deg. cent. ionization starts at a minimum stress of 8.61 kv. per cm. (21.8 volts per mil). With lesser thickness of insulation, ionization would not have started at such low stress, but it is apparent that in any badly bulged coil there is danger of ionization under normal operating conditions.

EFFECT OF INTERNAL IONIZATION

The damage caused by internal ionization in samples of rectangular cross section having various types and thicknesses of insulation has been studied for the past four years. The samples are over stressed for long periods of time, some continuously, others intermittently to produce "breathing" effect.

The result can be summarized by saying that without exception a chemical analysis[10] of the deteriorated material deposited on the walls of the gas spaces showed it to be a nitro-product. Exactly the same effect is produced by the attack of nitric acid. This can only mean that some source of air supply was available and the conclusion is that air was supplied through the capillary passages.

In general the degree of damage depended upon the ability to supply fresh air. The damage in loose porous samples was much greater than in compact ones. Likewise it was greater in those compact samples operated intermittently, where "breathing" supplied additional air. Another feature was that the voltage stress at which ionization started seemed to be independent of the degree of damage. There was no decrease in the starting voltage as the damage progressed.

We have never tested impregnated paper cable in this way. There is no source of air supply in lead sheathed cable and such a test would be interesting.

ACKNOWLEDGMENT

In concluding this paper, we wish to express our appreciation and thanks to Dr. C. P. Steinmetz and Messrs. W. S. Clark,

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[10] Thanks are due to Dr. C. G. Van Brunt who analyzed these materials.

H. G. Reist, E. Knowlton, D. A. Ballard, H. L. Schermerhorn, and W. C. Hayman for their cooperation and helpful advice.

APPENDIX

For a concentric cross section, such as a single-conductor sheathed cable, the effective a-c. resistivity per cm³., (average through thickness of insulation) can be calculated by the following formula:

$$\rho_{av.} = \frac{2\,\pi\,l\,E^2}{W\,\log_\epsilon \dfrac{b}{a}} \qquad (\mathbf{1})^{11}$$

where, $\rho_{av.}$ = average effective a-c. resistivity per cm.³
l = length of sample considered in cm.
a = radius of conductor in cm.
b = radius of inner side of metal jacket in cm.
E = impressed volts (effective)
W = watts dielectric loss in length, l.

For the same conditions above the relative permittivity (average through thickness,) is:

$$K_{av.} = \frac{I \sin\theta \cdot \log_\epsilon \dfrac{b}{a}}{(2\,\pi)^2\,l\,f\,E\,K_a} \qquad (\mathbf{2})$$

where, I = amperes, dielectric current for length, l.
θ = dielectric power factor angle.
f = frequency.
K_a = capacity per cm³ of air = 0.08842×10^{12} farads.

With the following nomenclature and that already given the formula for concentric cross sections having dielectric layers of different permittivities is derived below:

g = voltage gradient $\left(\dfrac{d\,e}{d\,x}\right)$ at radius x.
C = capacity in farads = $\dfrac{I \sin\theta}{2\,\pi\,f\,E}$
$b_1, b_2 \ldots\ldots b_n$ = radius in cm. to outer surface of layers.
K = relative permittivity at radius x.
$K_1, K_2 \ldots\ldots K_n$ = relative permittivity of layers.

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[11] For derivation of this formula see, "Insulation Characteristics of High Voltage Cables," Clark and Shanklin, loc. cit.

$$\frac{1}{C} = S = S_1 + S_2 \ldots\ldots\ldots + S_n$$

$$S = \frac{1}{2\,\pi\,l\,K_a}\left(\frac{\log_\epsilon \frac{b_1}{a}}{K_1} + \frac{\log_\epsilon \frac{b_2}{b_1}}{K_2} \ldots\ldots\ldots + \frac{\log_\epsilon \frac{b_n}{b_{n-1}}}{K_n}\right)$$

$$d\,s = \frac{1}{K} \cdot \frac{1}{2\,\pi\,l\,K_a} \cdot \frac{d\,x}{x}$$

$$d\,e = \frac{I \sin\theta\, d\,s}{2\,\pi\,f} = \frac{E}{S} \cdot \frac{1}{K} \cdot \frac{1}{2\,\pi\,l\,K_a} \cdot \frac{d\,x}{x}$$

$$g = \frac{d\,e}{d\,x} = \frac{E}{S} \cdot \frac{1}{K} \cdot \frac{1}{2\,\pi\,l\,K_a} \cdot \frac{1}{x}$$

$$g = \frac{1}{x\,K}\left(\frac{E}{\frac{\log_\epsilon \frac{b_1}{a}}{K_1} + \frac{\log_\epsilon \frac{b_2}{b_1}}{K_2} \ldots\ldots + \frac{\log_\epsilon \frac{b_n}{b_{n-1}}}{K_n}}\right) \tag{3}$$

When $a = \alpha$ the dielectric lines are parallel between plane surfaces.

$$t_1 = b_1 - a \qquad t_2 = b_2 - b_1 \qquad t_n = b_n - b_{n-1}$$

$$g = \frac{E}{K\left(\frac{t_1}{K_1} + \frac{t_2}{K_2} \ldots + \frac{t_n}{K_n}\right)} \tag{4}$$

In calculating the maximum voltage gradient between conductor and sheath in a three conductor cable it is assumed that g_{max} is not influenced by the proximity of the other two conductors. The problem then simplifies to the determination of g_{max} for two eccentric conductors.

a = radius in cm. of conductor.
b = radius in cm. to inside surface of sheath.
d = distance in cm. between axis of a and b.
g_{max} = voltage gradient (volts/cm.) at surface of cond.

From Russell's "Alt. Currents", Vol. 1, pp. 169-170.

$$g_{max} = \frac{E}{a\ \omega}\left[\frac{b^2 - (a - d)^2}{b^2 - (a + d)^2}\right]^{1/2} \qquad (5)$$

where,

$$\omega = 2 \log_\epsilon [\sinh (\omega/2) + \cosh (\omega/2)]$$

and,

$$\sinh (\omega/2) = \left[\frac{(S - a)\ (b - S)}{a\ b}\right]^{1/2}$$

$$\cosh (\omega/2) = \left[\frac{S\ (S - d)}{a\ b}\right]^{1/2}$$

where,

$$S = \frac{a + b + d}{2}$$

The relative permittivity (K_{av}) of the insulation between conductor and sheath of a three conductor cable is determined as follows:

Let,

a = radius in cm. of conductor.
b = radius in cm. to inside surface of sheath.
d = distance in cm. between axis of a and b.
c_1 = 1/3 the total measured capacity between the three conductors in parallel and sheath, in farads per ft. length of cable.

From Alex. Russell's, "Alt. Currents" Vol. 1, p. 193.

$$K_{av} = 5.904 \times 10^{10}\ c_1 \log_\epsilon \frac{b^6 - d^6}{3\ (b^3\ d^2\ a)} \qquad (6)$$

To be presented at the 7th Midwinter Convention of the American Institute of Electrical Engineers, New York, February 21, 1919.

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(*Subject to final revision for the Transactions.*)

ABNORMAL VOLTAGES WITHIN TRANSFORMERS

BY L. F. BLUME AND A. BOYAJIAN

Abstract of Paper

Mathematical analysis is made of a rectangular wave impinging upon a transformer winding and quantitative values deduced of the resulting internal voltage stresses in terms of transformer constants. It is shown that the conclusions also apply in part to abrupt impulses and approximate idea is given of the reaction of transformer to high frequencies. The difference between operating transformer with isolated and grounded neutral is shown. Energy losses are not considered in the mathematics although the manner in which the results are affected is pointed out. Finally, theoretical results are compared with impulse and high-frequency tests made in the laboratory.

I.—Introduction

To avoid breakdown of transformers resulting from abnormal voltages, the present practise is to either safeguard the transformer winding by external protective devices which are designed to prevent line disturbances from reaching the transformer, or to insulate the windings to withstand them. A third but less obvious method is so to design the transformer that voltage disturbances entering the winding will not result in excessive voltage concentration.

By showing in what way the transformer constants influence the voltage concentration this paper indicates how a transformer may be so designed as to mitigate the stresses occasioned by a given voltage disturbance.

II.—Conclusions

Theory and experiment both of which are fully described later in the paper confirm the following conclusions.

1. Transformers differ from transmission lines on account of the presence of coil-to-coil capacitance and mutual inductance.
2. Three kinds of disturbances are recognized:
   A—abrupt impulses: B—rectangular waves with long tails: C—high-frequency voltages sustained and damped.

Manuscript of this paper was received December 12, 1918.

A. ABRUPT IMPULSES

3. The presence of coil capacitance causes the transformer to respond as a capacitance and not as an inductance to abrupt impulses and towards all frequencies* above its lower natural frequencies of oscillations.

4. The voltage distribution within the transformer windings for abrupt impulses and for high frequencies depends upon the factor,

$$\alpha = \sqrt{\frac{C_g}{C_s}}$$

where C_g is the total capacitance of winding to ground and C_s is the total coil capacitance from one end of the coil stack to the other.

5. The greater the value of alpha, the greater the concentration of voltage at the line end and the smaller the voltage in the interior of the winding. The maximum volts per unit length of coil stack at the line end is equal to alpha times the value of the voltage corresponding to uniform distribution. In high-voltage power transformers of disk high-voltage, and concentric-barrel low-voltage windings, the value of alpha varies from 5 to 30.

6. The more abrupt the impressed impulses, or the higher the impressed frequency, the greater is the concentration of voltage at the line ends. The maximum voltage expressed in the preceding paragraph corresponds to a perpendicular wave front or infinite frequency impressed.

7. If the turns are uniformly distributed throughout the windings, alpha is also the factor giving the concentration of the volts per turn at the line end; but on account of extra turn insulation, the usual practice is to considerably reduce the number of turns on the end coils.

As the voltage concentration in the end coils depends upon the value of series and ground capacitances and is independent of the number of turns, it follows that the volts per turn on the end turns is inversely as the number of turns per coil. For this reason it is evident that extra turn insulation will be effective only when it is so designed that the increase in dielectric strength is greater than the increase in voltage concentration.

8. For abrupt impulses and for very high-frequency

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*See paragraph 15.

oscillations it is immaterial whether the neutral is isolated or grounded.

B. RECTANGULAR WAVES WITH LONG TAILS

9. If the impulse has a long tail, the phenomena within the transformer will be initially as described in paragraphs 1 to 5 above, followed by a series of damped oscillations, the amplitudes of these oscillations depending not only on the amplitude of the impressed wave but also on the value of alpha, and on whether the neutral is isolated or grounded.

10. In addition to being proportional to the value of the impressed wave the amplitude of oscillation for a given harmonic is smaller the higher the harmonic and the smaller the value of alpha.

11. There is no simple relation between wave length and frequency and on that account waves cannot penetrate into a transformer winding without distortion.

12. As these oscillations occur simultaneously within the transformer windings, the resultant voltage distribution at any instant is obtained by re-combining the harmonics at that instant.

13. For isolated neutral and for alpha equal to 10, a maximum of 2.8 times impressed volts exists from neutral to ground and the volts per turn in the interior of the windings is approximately four times normal.

14. For grounded neutral and for alpha equal to 10, a maximum of 1.5 times impressed volts exists from the windings to ground, and the volts per turn in the interior of the windings is increased to four times normal and at the neutral to 7.5 times normal.

C. HIGH FREQUENCY

15. When the applied high frequency is greater than the natural frequency of the transformer, the reaction of the transformer is similar to its reaction towards abrupt impulses, and paragraphs 3 to 8 apply.

16. Theoretically, by impressing a sustained high frequency voltage across transformer terminals at a natural oscillating frequency of the windings, the transformer can be made to resonate and indefinite voltages built up limited only by internal losses. However, if the transformer is excited by a transmission line, the voltage built up by resonance is also

limited by the relative values of surge impedance of transformer and line.

17. However in the high frequency tests here reported extreme high voltages were not observed. This is probably due to the following reasons:

(a) The impressed high frequency was highly damped.
(b) The presence of internal capacitances shunting the windings decreases the rapidity with which the voltage is accumulated.
(c) Internal losses within the transformer windings.

18. The effects of (b) and (c) are greater the higher the frequency of oscillation. For this reason high internal voltages are built up, only at the lower frequencies.

III.—Description of Phenomena

The theory of electrical waves in transmission lines cannot be directly applied to transformers due to the fact that a transformer, unlike a transmission line, possesses capacitance between coils and mutual inductance.

Assuming that the inductance and capacitances are uniformally distributed along the winding as diagrammatically represented in Fig. 1, mathematical analysis can readily be applied, but if the constants are bunched as is the case for transformers in which the high and low voltage windings are interlaced, the problem becomes very complicated.

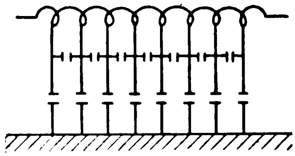

Fig. 1

A good example of a concentric winding transformer to which the conclusions of this report are applicable is given in Fig. 4. This is a three-phase 2500-kv-a. transformer, the 100,000-volt winding of which is Y connected and made up of three stacks of disk coils. It is necessary to assume that the capacitances between turns and layers are very large compared with capacitances between coils and ground to make Fig. 1 applicable.

The purpose of this paper is to show what takes place within the transformer windings under the impact of rectangular waves. Rectangular waves are chosen rather than periodic waves on account of the greater simplicity of the problem, and

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*See *Abnormal Voltages on Transformers*, by J. M. Weed, A. I. E. E. Trans. 1915, p. 1621.

waves of long duration (long compared with the time of a complete oscillation within the transformer) are assumed because the resulting voltages are greater than with the very short waves or impulses.

In general there will be two cases requiring separate treatment depending upon whether the neutral is isolated or grounded.

Although the phenomena with which we are dealing involves in its entirety only a very small fraction of a second, it is nevertheless convenient to divide it into three distinct time periods, each requiring separate treatment. These will be designated; 1, initial period; 2, transient period; 3, final period.*

The initial period is the period from the beginning of the disturbance to the time of maximum applied voltage. The time involved is so small that there is no appreciable growth of magnetic flux and therefore the phenomena may be considered entirely electrostatic without appreciable error. This is followed by a transient period during which there is a continual interchange of energy between the electric and magnetic fields. The energy interchange usually takes the form of highly damped high-frequency voltage and current oscillations. When the oscillations become negligible the final period has been reached in which the winding has again assumed a permanent condition of equilibrium.

TRANSFORMER REACTING AS A CONDENSER

Due to the combination of coil and ground capacitances, the transformer, during the initial period, reacts as a concentrated capacitance. The condensers are rapidly charged and the voltage across them rises to nearly double the voltage of the incoming wave. The time required for charging is so very small that it is safe to assume that twice the voltage of the incoming wave is applied to the terminals of the transformer windings before an appreciable inductive current can be established in the windings. The equivalent or effective capacitance of the transformer, while being charged, is approximately given by equation (**21**),

$$C_{eff} = \sqrt{C_g \times C_s} \qquad \textbf{(21)}$$

where C_g is the total capacitance of the surface of transformer

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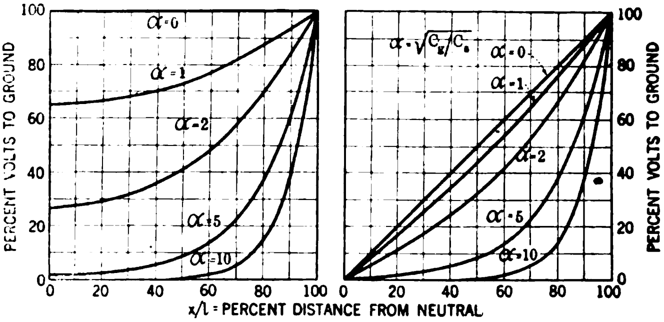
*See paper by Karl WillyWagner entitled "Progress of Waves in Windings." *Elektrotechnik und Maschinenbau.*" Feb. 21, and 28th, 1915.

winding to ground, C_s is the capacitance between the two ends of the winding. The calculation of the latter capacitance is simplified by assuming that the ends of the winding are electrically connected to clamping plates or end rings. C_s is then defined as the capacitance between these plates.

INITIAL VOLTAGE DISTRIBUTION

The voltage distribution throughout the transformer winding when the condensers are charged is given by formula (**11b**) for isolated neutral, and formula (**13b**) for grounded neutral.



NEUTRAL ISOLATED
PER CENT VOLTAGE TO GROUND =

$$\frac{e}{E_0} = \frac{\cosh\left(\alpha \frac{x}{l}\right)}{\cosh(\alpha)}$$

FIG. 2

NEUTRAL GROUNDED
PER CENT VOLTAGE TO GROUND =

$$\frac{e}{E_0} = \frac{\sinh\left(\alpha \frac{x}{l}\right)}{\sinh(\alpha)}$$

FIG. 3

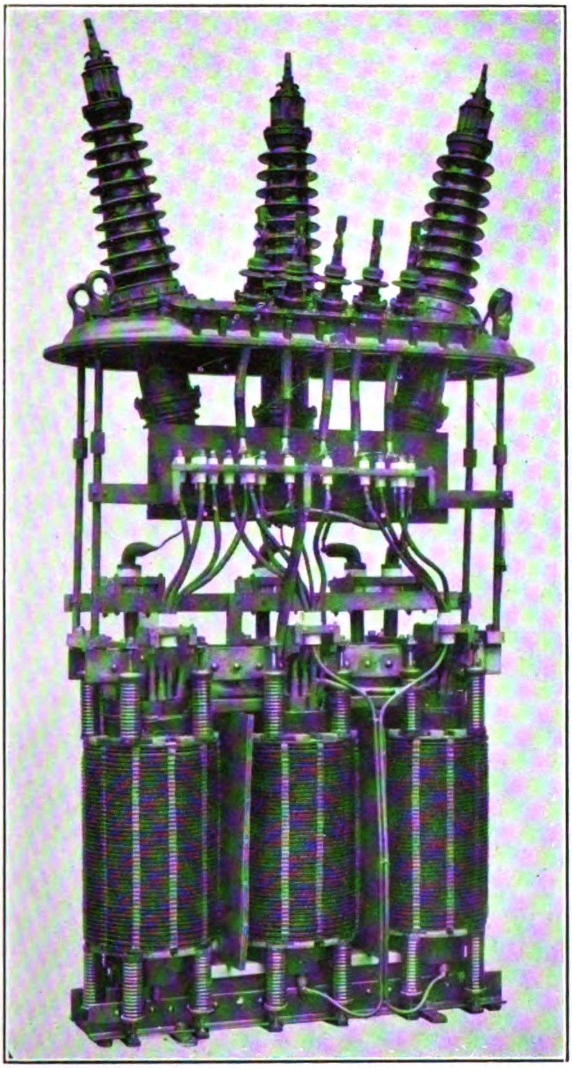
INITIAL VOLTAGE DISTRIBUTION IN WINDINGS FOR STEEP WAVE FRONT

$$e = E_0 \frac{\cosh \frac{\alpha x}{l}}{\cosh \alpha} \qquad \textbf{(11b)}$$

$$e = E_0 \frac{\sinh \frac{\alpha x}{l}}{\sinh \alpha} \qquad \textbf{(13b)}$$

where E_0 is value of voltage to ground on the transformer terminals. This will be either twice the value of the incoming wave, or, if lightning arresters are assumed, the maximum voltage permitted by the protective device.

The value of alpha is the square root of the ratio of the ground capacitance (C_g) to coil capacitance (C_s).



[BLUME AND BOYAJIAN]

FIG. 4—THREE-PHASE—60-CYCLE—2500 KV-A.—100,000-VOLT TRANSFOMER

Plotting the ratio e/E_0 as ordinate and the ratio x/l as abscissa gives the system of curves shown in Figs. 2 and 3. For alpha equals zero, that is, ground capacitance zero, the curve is a straight line (uniform voltage distribution). The greater the value of alpha the less uniform becomes the voltage distribution and the more is the voltage concentrated at the end of the winding. This is the reason for the modern practice of putting extra insulation on the coils and turns at the line ends.

It should be noted that these curves are based on windings in which the turns are uniformly distributed along the coil stack. On account of the space required by the extra end turn insulation it follows that there are fewer turns per unit length of coil stack at the ends of the windings. The effect of this is to cause a still greater concentration of voltage at the ends.

FINAL VALUE OF VOLTAGE DISTRIBUTION

(a) Eventually, in case of isolated neutral, the voltage of the winding will be brought to a potential of twice the original value of the wave with zero current flowing.

(b) For the case of grounded neutral the final condition will be a straight line with neutral at ground potential and line at twice the voltage of the original wave, with a current in the winding increasing at a constant rate, (assuming no resistance).

TRANSIENT VOLTAGE DISTRIBUTION

The transient by which the voltage distribution changes from the initial to the final value can be analyzed into a complex series of damped oscillations or standing waves at various frequencies, wave lengths and damping factors.

The maximum values of these standing waves are readily obtained by analyzing the initial voltage distribution as given in curves Fig. 2 into space harmonics with respect to the final voltage distribution as axis of reference. Thus we have for $\alpha = 10$ the following initial values of the standing waves.

NEUTRAL ISOLATED		NEUTRAL GROUNDED.	
Wave length on winding n	Amplitude in per-cent of line to ground voltage En/E_0	Wave length on winding. n	Amplitude in per cent of line to ground voltage e/E_0
1/4	125%	1/2	58%
3/4	34%	3/2	23%
5/4	15%	5/2	6%
7/4	7%	7/2	4%
9/4	3%	9/2	3%

These oscillations at various frequencies occur simultaneously within the transformer windings and the complex wave at a given time is obtained by recombining the harmonics at that time (Fig. 5).

The equation of any standing wave in a transformer winding. is

$$e_x = E_n \operatorname{Sin}\left(2\,\pi\, n\,\frac{x}{l}\right)\cos w_n t$$

or (33d)

$$e_x = E_n \operatorname{Cos}\left(2\,\pi\, n\,\frac{x}{l}\right)\cos w_n t$$

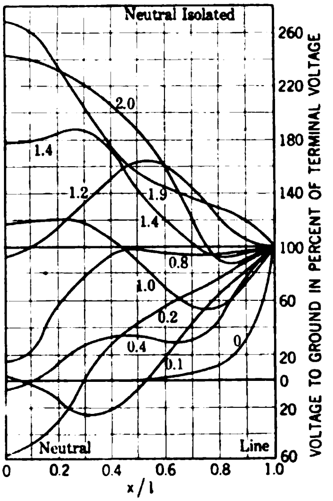


Fig. 5—Voltage Distribution within Transformer Windings at Various Times after Impact of Rectangular Wave

where n is the number of wave lengths per harmonic along the stack. For the fundamental, n is ½ when neutral is grounded, and ¼ when neutral is isolated. The frequency of oscillation is given by the equation:

$$f = \frac{2\,\pi\, n^2}{\sqrt{L\,(C_g + 4\,\pi^2\, n^2\, C_s\,)}} \qquad \textbf{(35e)}$$

These equations are particular solutions of the general differential equations and are derived under the heading of "Mathematical Development."

An inspection of formula (**35e**) shows that the natural frequencies are a function of the wave lengths. For $\alpha = 10$ the variation of wave lengths with frequency is as follows:

NEUTRAL ISOLATED		NEUTRAL GROUNDED	
Wave length	Relative * frequencies	Wave length	Relative * frequencies
n		n	
1/4	1	1/2	4
3/4	8	2/2	14
5/4	20	3/2	28
7/4	33	4/2	42
9/3	47	5/2	56

*These figures are not accurate due to the variation of inductance with wave length as discussed on another page.

This peculiar relation between frequency and wave length is due to the presence of coil capacitance and mutual inductance, and causes a continual change in the form of the complex wave from instant to instant. This is in marked contrast to the phenomena which take place in the transmission line, where a complex wave of any shape will be propagated without distortion, except for the effect of resistance.

Maximum Voltage to Ground and Maximum Volts Per Turn

The considerations of greatest interest in connection with these curves are the maximum voltages to ground and the maximum volts per turn at various points within windings. These are plotted in Figs. 6 and 7. Of course the maximum values of voltages at the various points do not occur at the same instant.

An inspection of these curves shows that, for the case of isolated neutral, the maximum voltage to ground occurs at the neutral and is equal to 2.8 times the voltage from line to ground and for grounded neutral the maximum volts to ground is 1.5 times line to ground voltage. The volts per turn for isolated neutral is 10 times normal at line end, 4 times normal in the major portion of winding, and zero at the neutral. With neutral grounded it is 10 times normal at line end 5 times normal in the major portion of the winding and 7.5 times normal at the neutral.

SURGE IMPEDANCE

In order to have a convenient means of calculating the maximum value of current associated with each oscillation the ratio of terminal volts to maximum current is given by

$$Z = \frac{E}{I} = \frac{1}{2\,\pi\,n}\sqrt{\frac{L}{C_g + 4\,\pi^2\,n^2\,C_s}} \qquad \textbf{(39b)}$$

The value of surge impedance calculated for the transformer shown in Fig. 4 is 60,000 for the fundamental, 29,000 for the third harmonic, 17,000 for the fifth harmonic and 12,000 for the seventh harmonic.

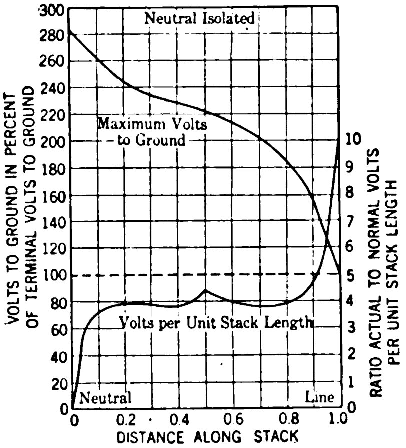


FIG. 6—VOLTAGE DISTRIBUTION WITHIN TRANSFORMER WINDINGS MAXIMUM VALUES AFTER IMPACT OF RECTANGULAR WAVES

In the analysis just given it has been tacitly assumed that the voltage E applied across the terminals of the transformer winding is maintained throughout the oscillations. Strictly speaking, this is not true, because during the time when the voltage to ground is increasing in the interior of the winding, the transmission line is delivering current to the transformer windings, and during the time when this voltage to ground is decreasing, the transmission line is receiving current from the transformer windings, or in other words, there is a continual interchange of energy between the transmission line and the winding throughout the oscillation, and as the ratio of voltage to current associated in the rectangular wave in the transmission line is a constant value, this interchange of energy cannot take place without modifying the line voltage. However, calculations of equivalent surge impedance show that in all practical transformers the amount of energy absorbed and delivered by the transformer windings is very small compared with the energy residing in the rectangular wave, and that, therefore, this fluctuation in voltage is negligible in amount.

Again it may at first appear that the axis of oscillation taken in the case of a grounded-neutral transformer, cannot be correct because the final condition for the case of grounded neutral is zero voltage throughout the windings owing to the fact that the windings become a dead short circuit. This is again theoretically true but it has no bearing on the problem because in all practical cases the time taken for the transformer windings to degenerate into a short circuit is so very long compared with the time involved in the oscillation of the fundamental frequency that it can be safely assumed that the transformer winding oscillates through a complete cycle of the fundamental before the voltage applied to the terminals of the transformer windings can be appreciably lowered.

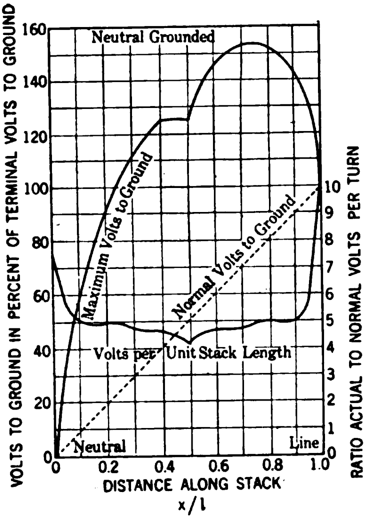


FIG. 7—VOLTAGE DISTRIBUTION WITHIN TRANSFORMER WINDINGS MAXIMUM VALUES AFTER IMPACT OF RECTANGULAR WAVE

NATURAL FREQUENCY OF OSCILLATION OF A WINDING

Formula (**35e**) is useful for the purpose of obtaining the natural frequency of a winding. For a solenoid consisting of a single one-layer coil, the capacitance between turns may be neglected and the formula becomes.

$$f = \frac{2\,\pi\,n^2}{\sqrt{L\,C_g}} \qquad \textbf{(35f)}$$

From this equation we reach the very interesting conclusion that the natural frequency of oscillations are not simple multiples of the fundamentals in the order of 1, 2, 3, 4, etc., but that they are proportional to the square of these values that is 1, 4, 9, 16, etc., (neglecting the variation of inductance with wave length.)

If the capacitance between turns or coils is not negligible the formula reverts to equation (**35e**). The influence of coil capacitance is to make the natural frequencies lower than those given by formula (**35f**). Moreover, the harmonics are not simple multiples of the fundamental in every case.

At very high frequencies the influence of ground capacitance becomes negligible compared with series capacitance and the formula for frequency becomes,

$$f = \frac{n}{\sqrt{L\,C_s}} \qquad \textbf{(35g)}$$

DAMPING FACTORS

Of course the voltage distribution as given in Fig. 5 departs considerably from what occurs in practise on account of dielectric losses, which introduce a damping factor, which is greater the higher the frequency.

It may be, therefore, especially where the order of frequencies progresses as the square of the wave lengths, that before the fundamental has completed one-half of a complete oscillation most of the higher frequencies have become negligible. A knowledge of the dielectric losses would be necessary to determine whether the voltage stresses are appreciably restricted by them.

HIGH FREQUENCY TRANSIENTS

An idea of the transient phenomena occurring within a transformer winding when sustained high frequency is impressed can best be obtained by considering the applied high frequency to be made up of successive positive and negative rectangular waves, the frequency of which is the same as the fundamental frequency of the transformer winding. During the time of the first half cycle phenomena are as described above. When the applied wave changes from positive to negative, the voltage to ground within the transformer winding due to the fundamental has reached its maximum value. The effect of this change in applied voltage is to increase the amplitude of the fundamental approximately by twice the amplitude of the applied voltage. In the example given the above fundamental has a value of 1.24 times the terminal applied voltage for the case of isolated neutral. At each cycle this value is increased by twice the value of the terminal voltage, causing the voltage to ground to increase regularly in steps so that the maximum potential to ground at the end of the second half cycle is 4.72, at the end of the third half cycle 7.20 etc.

The above assumes that the internal losses are insufficient to reduce its amplitude and neglects the amplitude of all other harmonics. Of course, if the applied frequency happens to be equal to the frequency of one of the harmonics the building up of voltage by resonance as described above would apply to that harmonic and not to the fundamental.

It should be noted that the amplitude of the oscillations within the transformer winding are not necessarily the amplitude of the impressed voltage, but they depend upon the amplitude of impressed wave voltage and also upon the values given in the table under "Transient Voltage Distribution." These values are dependent upon the value of "α"; the smaller the value of "α" the smaller will be the value of internal oscillations, and moreover, for a given value of "α" the amplitudes of the oscillations are smaller for the shorter wave lengths.

However, when a sustained high frequency, or a damped oscillation, having a frequency equal to a natural frequency of the transformer, is impressed, the resulting stress as previously shown may very greatly exceed those given by the curves, the values being limited by the value of "α", the internal losses, and the damping factor of the impressed wave. For a reliable quantitative analysis an accurate knowledge of all these factors is necessary.

IV.—Impulse Tests on Small High-Voltage Transformer Winding

A 30,000-volt transformer winding made up of a stack of 52 disk coils approximately 15 in. long and 10 in. in diameter was

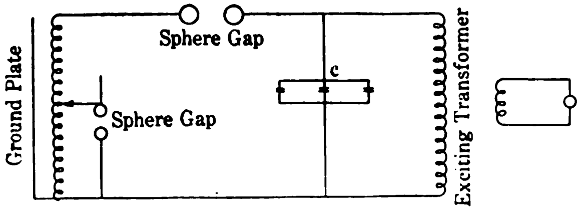


FIG. 8—IMPULSE TESTS ON SMALL HIGH VOLTAGE TRANSFORMER-CONNECTION DIAGRAM

used for these tests. Grounded metal cylinders were placed inside and outside of the stack, to simulate low-voltage winding and tank.

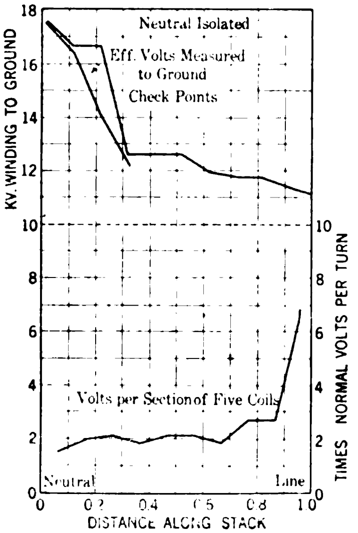


FIG. 9—IMPULSE TESTS ON SMALL HIGH VOLTAGE TRANSFORMER—FOR CONNECTIONS SEE FIG. 8

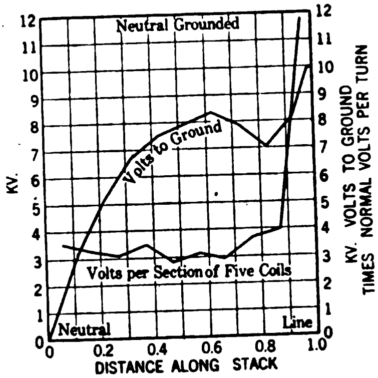


FIG. 10—IMPULSE TESTS ON SMALL HIGH VOLTAGE TRANSFORMER

The connection used in testing is shown in Fig. 8. Voltage was applied from line to ground; in some tests the neutral (one end) of the coil was grounded to the metal cylinders and in the other test isolated. A spark gap *A* was connected in series with the coil, and a large condenser *C* in multiple with it. The operation is as follows: As the voltage rises, it charges the condenser *C*. This voltage also appears across the gap *A*, a very small part being consumed in the capacitance of the coil. When the gap arcs over, the entire voltage, abruptly applied across the winding, gives rise to a series of oscillations, within the winding. The use of the condenser *C* (which must be as large as practicable) is to maintain the applied voltage while the capacitance of the coil is being charged and also to allow an easy return path for the high frequency oscillations set up in the coil. As these oscillations die out before the 60-cycle voltage has appreciably changed, the impressed voltage is in effect a sustained rectangular wave.

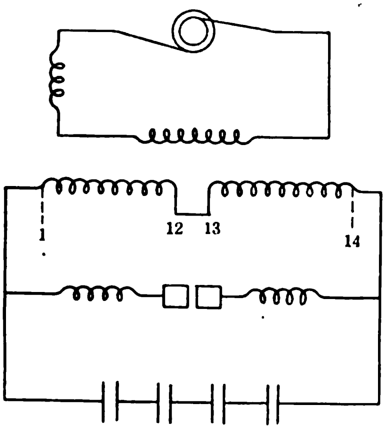


Fig. 11—High-Frequency Investigation—60 Cycles—3000 Kv-a.—140,000 Volts—Diagram of Connections

The voltage to ground and the voltage gradients are plotted in Fig. 9 and Fig. 10.

Constants of the Coil

Ground capacitance $C_g = 12 \times 10^{-10}$ farads.
Series capacitance $C_s = 4.4 \times 10^{-12}$ farads.

$$\alpha = \sqrt{\frac{C_g}{C_s}} = 16.5$$

V.—High Frequency Tests*

High-frequency tests on the high-voltage windings of 3000-kv-a. 140,000-volt transformer (Fig. 4) compared with theoretically calculated stresses resulting from impact of rectangular waves.

Transformer constants;

C_g = Ground Capacitance = 9×10^{-4} microfarads.
C_s = Coil Capacitance = 9×10^{-6} microfarads.

$$\alpha = \sqrt{\frac{C_g}{C_s}} = 10$$

Connection diagrams for these tests are given in Fig. 11, and high frequency voltages obtained across taps are plotted in Fig. 12 and Fig. 13. In Fig. 14 is plotted the approximate volts obtained by these tests at any frequency (curve marked by dots). For comparison the volts per turn as theoretically obtained for rectangular waves (See Fig. 6) and corrected for end turn insulation has been plotted on the same sheet (curve marked by crosses.) The theoretical values have been multiplied by two, for the following reason.

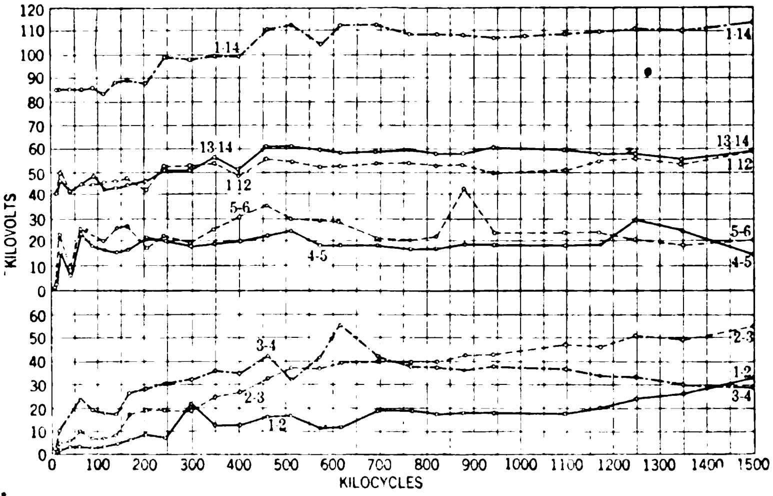


FIG. 12—HIGH FREQUENCY VOLTAGES MEASURED BETWEEN TAPS

Discharge takes place every one half wave at the maximum point of the wave. Condensers discharge into the inductive circuit, the maximum value of high-frequency voltage being equal to maximum value of the 60-cycle voltage. One-half wave of the high-frequency discharge is shown in Fig. 15. It is seen that during this half cycle the high-frequency voltage changes from maximum positive to maximum negative. The original 60-cycle voltage distribution, just before the arc-over, is the straight line shown in Fig. 16. Half a high frequency cycle after the arc-over, the resultant of the 60 cycle and high frequency voltage distribution is shown by curve "*a*" in Fig. 16, assuming that the frequency is high enough for the wind-

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*Tests made by J. M. Weed and J. E. Clem.

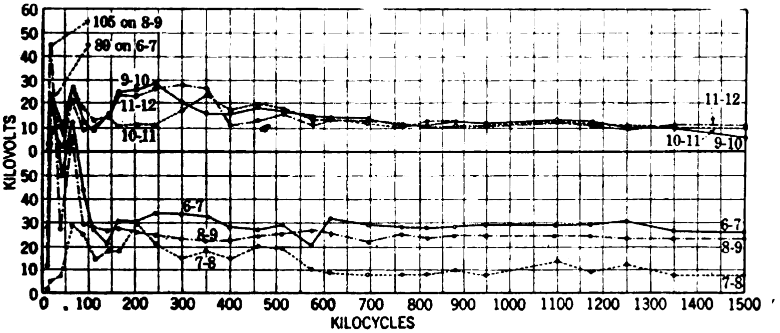

Fig. 13—High Frequency Voltages Measured between Taps

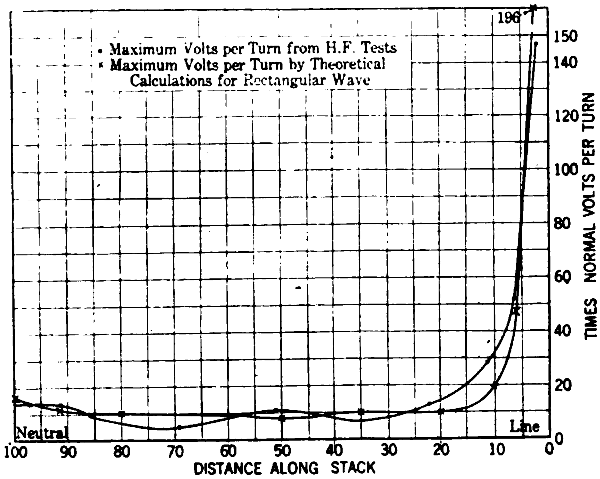

Fig. 14—3000 Kv-a.—140,000 Volt Transformer

ing to act as condenser for the first half cycle of the high-frequency wave. Thus it is evident that the combination of the high- and low-frequency waves doubles the voltage gradient.

HIGH FREQUENCY TEST DATA

Taps	Per cent turns	Per cent along stack	Maximum volts per turn times normal
1—2	.19	2.1	147 at 1,500,000 Cycle
2—3	1.2	6.3	52 1,500,000 "
3—4	4.	11.4	28 at 600,000 "
4—5	8.2	16.7	11 at 62,000 "
5—6	13.5	22.5	13.5 at 900,000 "
6—7	30.7	36	5.6 62,000 "
7—8	48	51.5	11.5 62,000 "
8—9	68	69	6 20,000 "
9—10	89	86	9.9 62,000 "
10—11	94	91.5	13 62,000 "
11—12	98	97	14 62,000 "

The volts per turn occurring at ends of windings are the same as if a rectangular wave of voltage 2 *E* had been applied. For this reason the values for volts per turn as theoretically obtained for rectangular waves have been multiplied by two in order to compare these values with the high-frequency test. The higher the frequency of test, the more nearly should the condenser volts per turn distribution equal twice the voltage distribution caused by a rectangular wave.

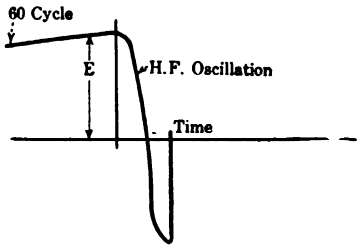

FIG. 15—TIME-VOLTAGE CURVE AT LINE END OF WINDING

V—Mathematical Development

1. Initial voltage distribution in a winding for a steep wave front.
2. Initial effective or equivalent capacitance of a winding for a steep wave front.

3. Time required to charge the initial effective capacitance of a winding.
4. Analysis of transient phenomena following the initial voltage distribution.
5. Surge impedance of an oscillating winding.
6. Example.

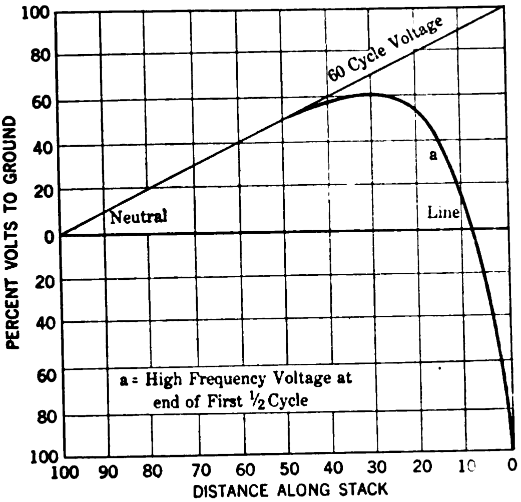

Fig. 16—Space-Voltage Curves for $t = 0$ and $t = \frac{1}{2}$ [High Frequency Cycle

1. Initial Voltage Distribution in a Winding for Steep Wave Fronts

If voltage is suddenly applied to a system of inductances in multiple with a system of capacitances, the initial voltage

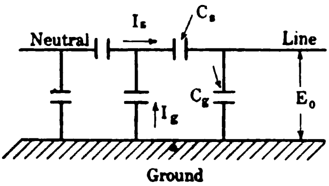

Fig. 17

distribution will be determined by the capacitances. At the instant of impact, the condensers short circuit the steep wave front. If the wave is maintained, the condensers become charged, and the voltage rises. The time required for this charging is extremely small as given by equation (**22**).

The voltage distribution, when the condensers are charged, is the same as that when an alternating voltage is applied to the system of condensers with the inductance disconnected. Considering the system of internal and ground capacitances by themselves (Fig. 17), and assuming an alternating voltage of frequency f, $\left(f = \frac{\omega}{2\pi}\right)$, applied, the following relations will be evident.

Let C_s = Capacitance between line end of coil and neutral, shunting the winding.

C_g = Capacitance between winding and ground for a coil length of line to neutral.

l = Coil length line to neutral.

$l\, C_s$ = Capacitance between portions of winding unit distance apart.

$\frac{C_g}{l}$ = Capacitance to ground per unit length of coil

e = Voltage to ground at any point.

$\frac{d\,e}{d\,x}$ = Voltage gradient, volts per unit length of coil.

E_0 = Impressed voltage line to ground.

ω = $2\pi f$ = angular velocity.

I_s = Current in the coil capacitance C_s.

$$= [\omega\, C_s\, l\, \frac{d\,e}{d\,x} \qquad (\mathbf{1})$$

I_g = Current in ground capacitance C_g per unit length of coil.

$$= \omega\, C_g\, \frac{e}{l} \qquad (\mathbf{2})$$

The increase per unit distance in the current of the shunt capacitance is the current supplied by the ground capacitance per unit length, that is,

$$\frac{d\,I_s}{d\,x} = I_g \qquad (\mathbf{3})$$

Substituting in equation (**3**) the value of $\frac{d\,I_s}{d\,x}$ from (**1**), and

I_g from (**2**), and simplifying,

$$\frac{d^2 e}{d x^2} - \frac{1}{l^2} \frac{C_g}{C_s} e = 0 \tag{4}$$

The solution of this equation is of the form

$$e = A \epsilon^{px} \tag{5}$$

Substituting (**5a**) and its derivative in (**4**), and solving for p,

$$p = \pm \frac{1}{l} \sqrt{\frac{C_g}{C_s}} \tag{6}$$

and

$$e = A \epsilon^{px} + B \epsilon^{-px} \tag{7}$$

The constants A and B are determined by the terminal conditions as follows.

Case I.—Neutral Isolated. If the neutral is isolated at $x = 0 \quad I_s = 0$ (**8**)

The value of I_s is, from (**1**) and (**7**).

$$I_s = \omega l C_s \frac{d e}{d x} \tag{9a}$$

$$= \omega l C_s (A \epsilon^{px} - B \epsilon^{-px}) \tag{9b}$$

Substituting, $x = 0$, and $I_s = 0$

$$0 = \omega l C_s p (A - B) \tag{10a}$$

$$A = B \tag{10b}$$

Substituting, (**10b**) in (**7**),

$$e = A (\epsilon^{px} + \epsilon^{-px}) \tag{10c}$$

$$= A' \cosh (p x) \tag{10d}$$

Now, at $x = l \quad e = E_0$ (**10e**)

$$e = E_0 \frac{\cosh (p x)}{\cosh (p l)} \tag{11a}$$

$$= E_0 \frac{\cosh \left(\frac{\alpha x}{l}\right)}{\cosh (\alpha)} \tag{11b}$$

where $\alpha = p l = \sqrt{\frac{C_g}{C_s}}$ and the neutral is isolated

Case II.—Neutral Grounded. The terminal conditions are

at $x = 0 \qquad e = 0$ (**12a**)

and at $x = l \qquad e = E_0$ (**12b**)

Applying condition (**12a**) to equation (**7**).

$$0 = A + B$$

$$A = -B$$

$$e = A\,(\epsilon^{px} - \epsilon^{\;px}). \qquad (\mathbf{12c})$$

$$e = A'\sinh p\,x \qquad (\mathbf{12d})$$

Applying condition (**12b**) to equation (**12d**)

$$E_0 = A'\sinh p\,l \qquad (\mathbf{12e})$$

$$A' = \frac{E_0}{\sinh p\,l}$$

Therefore, $e = E_0 \dfrac{\sinh p\,x}{\sinh p\,l}$ (**13a**)

$$= E_0 \frac{\sinh\left(\dfrac{\alpha\,x}{l}\right)}{\sinh\alpha} \qquad (\mathbf{13b})$$

where, $\alpha = p\,l = \sqrt{\dfrac{C_g}{C_s}}$ and the neutral is grounded.

Initial voltage distribution curves for both the isolated neutral and the grounded neutral are given in Figs. 2 and 3.

GENERAL REMARKS ON THE INITIAL VOLTAGE DISTRIBUTION

When the capacitance to ground is negligible compared with the capacitance between coils, that is, $C_g = 0$, the initial voltage distribution is determined by the series capacitances and is a straight line if the capacitance between coils is uniform.

As the capacitance to ground more and more predominates, the curve becomes steeper near the line end, that is, the voltage is concentrated more and more near the line end.

The voltage gradient (volts per unit length) is $e_s = \dfrac{d\,e}{d\,x}$

$$= \frac{\alpha\,E_0 \sinh\left(\dfrac{\alpha\,x}{l}\right)}{l\cosh\alpha} \text{ neutral isolated} \qquad (\mathbf{14a})$$

$$= \alpha\,\frac{E_0}{l}\,\frac{\cosh\left(\dfrac{\alpha\,x}{l}\right)}{\sinh\alpha} \text{ neutral grounded} \qquad (\mathbf{14b})$$

The maximum voltage gradient is at the line end, $x = l$,

$$e_s = \frac{\alpha E_0 \sinh \alpha}{l \cosh \alpha} \text{ neutral isolated} \qquad \textbf{(15a)}$$

$$= \alpha \frac{E_0}{l} \tanh \alpha \text{ neutral isolated} \qquad \textbf{(15b)}$$

Similarly $e_s = \alpha \dfrac{E_0 \cosh \alpha}{l \sinh \alpha}$ neutral grounded **(16a)**

$$= \alpha \frac{E_0}{l} \coth \alpha \text{ neutral grounded} \qquad \textbf{(16b)}$$

For "α" greater than 3,
Tanh α = coth α = 1
This is true for most transformers, and the voltage gradient at the line end becomes $\left(\dfrac{\alpha E_0}{l}\right)$ volts per unit length.

If the voltage were uniformally distributed throughout the winding, the gradient would have been $\left(\dfrac{E_0}{l}\right)$. Therefore, when the total capacitance to ground is very much larger than the coil capacitance between neutral and line, the voltage gradient at the line end is α times the value corresponding to uniform distribution.

It will also be noticed that for values of α greater than 5, the initial voltage distribution for a steep wave front is practically the same for the case of isolated as for grounded neutral.

INITIAL EFFECTIVE CAPACITANCE OF A WINDING FOR A STEEP WAVE FRONT.

In calculating the time of charging the system of coil and ground capacitances by an incoming wave, it becomes necessary to know the effective capacitance of the combination, This is equal to the effective capacitance for alternating voltage.

Representing this effective capacitance by C_{eff}, line current by I, line voltage (a-c.) by E, frequency by "f".

$$I = 2 \pi f C_{eff} E \qquad \textbf{(17a)}$$

$$\text{or } C_{eff} = \frac{I}{2 \pi f E} \qquad \textbf{(17b)}$$

$$\text{But } I = I_s \text{ at } x = l \qquad \textbf{(17c)}$$

$$\text{and } I_s = 2 \pi f C_s l \left(\frac{d e}{d x}\right) \qquad \textbf{(17d)}$$

The value of $\left(\frac{d\,e}{d\,x}\right)$ must be taken from equation of initial voltage distribution.

Case I.— *Neutral Isolated.* By equation (**15b**) at $x = l$

$$\frac{d\,e}{d\,x} = \alpha\,\frac{E}{l}\tanh\alpha \tag{18a}$$

$$\text{and } I = 2\,\pi\,f\,C_s \times \alpha\,\frac{E}{l}\tanh\alpha \tag{18b}$$

Substituting (**18b**) in (**17b**).

$$C_{eff.} = \sqrt{C_g\,C_s} \times \tanh\alpha\text{, neutral isolated} \tag{19}$$

Case II.—*Neutral Grounded.* Solving similarly for the above case, but using equation (**16b**) instead of (**15b**),

$$C_{eff} = \sqrt{C_g\,C_s}\,\coth\alpha \tag{20}$$

As stated before, for values of α greater than 3, which is the case with most transformers, tanh α equals one, coth α equals one, and

$$C_{eff} = \sqrt{C_g\,C_s} \tag{21}$$

whether the neutral is grounded or isolated.

TIME REQUIRED TO CHARGE THE CONDENSERS TO THE INITIAL VOLTAGE DISTRIBUTION

The time required to charge a condenser by an incoming wave is given by the following formula, modified from one given by G. Faccioli in *G. E. Review*, 1914, page 749.

$$t = 2.3\,C_{eff}\,Z\log_{10}\left(\frac{100}{100 - \%\,E_0}\right)\text{ seconds.} \tag{22}$$

$C_{eff.}$ = Equivalent massed capacitance of the winding from line to neutral, calculated by formula, (**19**), (**20**), or (**21**).

Z = Surge impedance of the transmission line, and may be taken between 300 and 400.

$\%\,E_0$ = The actual terminal voltage in per cent of the final terminal voltage.

As an example, we will calculate the time necessary to charge the capacitance of the transformer described above to 90 per cent of its final value.

$C_g = 9 \times 10^{-10}$ farads.
$C_s = 9 \times 10^{-12}$ farads
$C_{eff.} = 9 \times 10^{-11}$ by formula (**21**)

Substituting this value of C_{eff} in (**22**) we obtain

$$t = 2.3 \times 9 \times 10^{-11} \times 300] \times \log_{10}\left(\frac{100}{100-90}\right)$$

$= 6.2 \times 10^{-8}$ seconds, which is about one twenty millionth of a second. It is justifiable, then, to assume that the initial voltage distribution by the condensers takes place before the inductance can begin to draw any appreciable current.

ANALYSIS OF TRANSIENT PHENOMENA FOLLOWING THE INITIAL VOLTAGE DISTRIBUTION

Let I_L = Current in the winding.
I_s = Current in the coil capacitance.
I_g = Current in the ground capacitance per unit length.

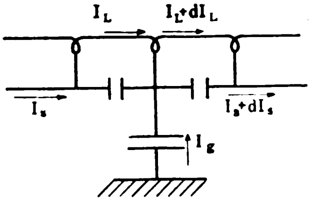

FIG. 18

The following relation will be evident from Fig. 18.

$$\frac{d\,I_L}{d\,x} + \frac{d\,I_s}{d\,x} - I_g = 0 \qquad \textbf{(23a)}$$

Equation (**23a**) states that the increase in the currents in the winding and the internal capacitance (as we go towards the line end) is equal to the current contributed by the ground capacitance, which is evident from Fig. 18.

For reasons that will be seen later, we differentiate (**23a**) with respect to t, and obtain

$$\frac{d^2 I_L}{dxdt} + \frac{d^2 I_s}{dxdt} - \frac{D\,I_g}{dt} = 0 \qquad \textbf{(23b)}$$

It will be noticed that equations (**23a**) and (**23b**) are true generally and are independent of what the initial or final voltage distributions may be.

Equation (**23**) involves three variables, I_L, I_g and I_s, and, before it can be solved, it must be expressed in one variable.

Since we are interested mostly in the voltages, we will express the variables in terms of voltages.

Let e = voltage to ground.
e_s = voltage gradient (volts per inch of coil) in the winding.
$= \dfrac{d\,e}{d\,x}$
N = Total turns (line to neutral)
φ = Total flux linking any turn.
φ_L = Leakage flux linking any turn.
φ_M = Main flux linking the total coil.
B_L = Leakage flux density at any point.
h = Effective length of leakage path.
L = Leakage inductance of coil.
(MLT) = Mean length of turn.
(For a complete list of symbols see the end of this paper.)

To Find the Relation Between I_s and Voltage. The current I_s in the capacitance between coils is equal to the capacitances per inch $l\,C_s$ times the rate of change of voltage per inch $\left(\dfrac{d\,e_s}{dt}\right)$.

$$I_s = l\,C_s \frac{d\,e_s}{dt} = C_s\,l \,\frac{d^2\,e}{dx dt} \tag{24}$$

$$\frac{d^2\,I_s}{dx dt} = C_s\,l \,\frac{d^4\,e}{dx^2\,dt^2} \tag{25}$$

Equation (**25**) can be directly substituted in equation (**23b**).

To Find the Relation Between I_g and Voltage. The current in the capacitance to ground I_g is equal to capacitance to ground per inch of coil C_g/l times the rate of change of voltage to ground.

$$I_g = \frac{C_g}{l}\,\frac{d\,e}{dt} \tag{26}$$

and

$$\frac{d\,I_g}{dt} = \frac{C_g}{l}\,\frac{d^2\,e}{dt^2} \tag{27}$$

Equation (**27**) can be directly substituted in (**23b**).

To Find the Relation Between I_L and Voltage. The relation between the magnetizing current (I_L) and the voltage is somewhat more complicated than that of the capacitance currents and voltage, due to the mutual inductance between turns and the presence of leakage and main fluxes. The connecting links between current and voltage to ground at any point x are current at x, ampere turns or magnetomotive force effective in producing leakage flux, flux density at point x, flux producing voltage at point x, volts per turn and volts. The mathematical relation between these physical quantities are as follows:

The voltage gradient e_s, *i. e.*, volts per inch, equals number of turns per inch N/l times the rate of change of total flux φ (= main flux φ_m + leakage flux φ_L). Thus,

$$e_s = \frac{N}{l}\frac{d\varphi}{dt}10^{-8} \tag{28a}$$

$$= \frac{N}{l}10^{-8}\frac{d}{dt}\left\{\varphi_L + \varphi_m\right\} \tag{28b}$$

The leakage flux (φ_L) linking x is obtained by integrating the leakage flux density (B_L). Thus,

$$e_s = \frac{N}{l}10^{-8}\frac{d}{dt}\left\{(MLT)\int_x^l B_L\,dx + \varphi_m\right\} \tag{28c}$$

If we differentiate (**28c**) with respect to x we get rid of the integral sign, and also of the last term because it is independent of x. Thus,

$$\frac{de_s}{dx} = -\frac{N}{l}10^{-8}(MLT)\frac{dB_L}{dt} \tag{29a}$$

The negative sign in (**29a**) is due to x being the negative limit of integration in (**28c**). Of course it could have been assumed of the opposite sign provided other signs were kept consistent with it.

The leakage flux density B_L in (**29a**) is produced by the ampere turns enclosed by the flux.

$$B_L = \frac{N\mu}{lh}\int_0^x I_L\,dx \tag{29b}$$

where $\mu = 4\,\dfrac{\pi}{10}$ when using dimensions in cm.

$= 3.2$, when using dimensions in inches.

$h =$ effective length of leakage path.

It may be questioned why in (**28c**) we use the limits $\int_x^l$ and in (**29b**) $\int_0^x$. The reason may be stated thus; the flux linking a current is outside of it, and the ampere turns producing the flux are inside of it. Therefore, if the total flux linking a certain point be integrated on the right of that point, the ampere turns producing that flux must be integrated on the left of the point. As a concrete example consider Fig. 19.

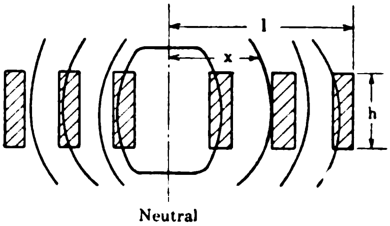

Fig. 19

The flux producing voltage in a turn at the point x is all the flux from x to l; but the ampere turns producing the flux at x are all the ampere turns from 0 to x.

Returning to the main problem, (**29b**) substituted in (**29a**) gives

$$\frac{d\,e_s}{d\,x} = -\,\frac{3.2\,N^2\,(MLT)}{l^2\,h\,10^8}\,\frac{d}{d\,t}\int_0^x I_L\,d\,x \qquad \textbf{(29c)}$$

$$= \frac{L}{l^3}\,\frac{d}{d\,t}\int_0^x I_L\,d\,x \qquad \textbf{(29d)}$$

where

$$L = \frac{3.2\,l\,N^2\,(MLT)}{h\,10^8} \text{ (See note opposite)} \qquad \textbf{(29e)}$$

Differentiating (**29d**) with respect to "x" eliminates the integral sign. Thus,

$$\frac{d^2 e_s}{d x^2} = - \frac{L}{l^3} \frac{d I_L}{dt} \qquad \textbf{(30a)}$$

Remembering that e_s (voltage gradient) is equal to $\frac{d e}{d x}$ (derivative of voltage to ground), (**30a**) becomes

$$\frac{d^3 e}{d x^3} = \frac{L}{l^3} \frac{d I_L}{dt} \qquad \textbf{(30b)}$$

(**30b**) gives the value of $\frac{d I_L}{dt}$, while, equation (**23a**) involves $\frac{d I_L}{d x}$. If we differentiate the former with respect to x and the latter with respect to t, substitution becomes possible. This is the reason why (**23a**) was differentiated with respect to time giving (**23b**).

Differentiating (**30b**) with respect to x and rearranging.

$$\frac{d^2 I_L}{dxdt} = \frac{-l^3}{L} \frac{d^4 e}{d x^4} \qquad \textbf{(31)}$$

(**31**), (**25**) and (**27**) express in terms of voltage the three terms of the fundamental differential equation (**23b**). Making the substitution, (**23b**) becomes

---

NOTE:—In discussing the leakage flux relations, we have assumed the effective length of the path as constant and independent of wave length. This is approximately true for only short waves on disk coils when the radial build of the coils is comparable to the wave length. Otherwise, the formula for L will not be accurate enough for numerical calculations. L, however, can be determined experimentally for various wave lengths as follows. Take one portion of the winding equal to one quarter of the wave length under consideration and short circuit it. Take an equal portion adjacent to it, excite it as primary, and measure its inductance (= Reactance/377 for 60-cycle test). Multiply this value of inductance by $32\, n^3$ to get the effective value of L for that wave length.

If the winding consists of disk coils, for approximate calculations the effective length of leakage path may arbitrarily be assumed as equal to the radial coil-build plus one-sixth of wave length:

$$h = b + \frac{l}{6\, n} \qquad \textbf{(29f)}$$

$$\frac{d^4 e}{d x^4} - \frac{L C_s}{l^2} \frac{d^4 e}{dx^2 dt^2} + \frac{L C_0}{l^4} \frac{d^2 e}{dt^2} = 0 \tag{32}$$

(**32**) is the general differential equation of electrical phenomena occurring in windings, except that it does not take into account resistance and dielectric losses.

A solution of this equation is

$$e = A \cos p\, x \cos \omega\, t. \tag{33}$$

Substituting in equation (**32**) gives

$$\omega = \pm \frac{p^2\, l^2}{\sqrt{L\,(C_0 + l^2\, p^2\, C_s)}} \tag{34}$$

These equations show that a transformer is capable of sinusoidal oscillations in space and time at various frequencies and wave lengths.

Determination of the Constants. The voltage distribution may be expressed as the sum of a transient and a permanent component. The permanent component is the final voltage distribution. For a d-c. voltage applied, the final voltage distribution is $N\,B$ (Fig. 20) for the case of neutral isolated, that is, the whole coil assumes the impressed voltage E_0 against ground. The actual initial voltage being given by the hyperbolic curve $O\,A\,B$, the transient component is the difference between $N\ B$ and $O\ A\ B$. Expressing the same relation in another way $O\,A\,B$ represents the actual voltage when referred to $O\,M$ as the axis of reference, but represents the transient component when referred to $N\,B$ (the line of equilibrium) as the axis of reference. For neutral grounded (Fig. 21) $O\,B$ represents the permanent or equilibrium line, and $O\,A\,B$ (referred to $O\,B$ as axis) represents the transient component of the voltage distribution.

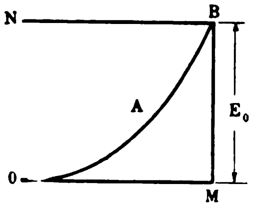

FIG. 20

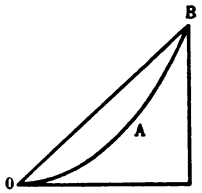

FIG. 21

To try to substitute the hyperbolic formula of initial voltage distribution in equation (**33**) leads to an indeterminate form, but if analyzed into space harmonics (with respect to the line of final voltage distribution), substitution is readily effected, and the actual voltage to ground is the sum of the harmonics and the voltage of the reference line to ground.

An inspection of Fig. 5 shows that for neutral isolated the initial voltage distribution curve $O\ A\ B$ is a quarter wave length (and its odd harmonics) with respect to the equilibrium line $N\ B$ with maximum voltage at the neutral. An inspection of Fig. 6 shows that for neutral grounded the initial voltage distribution curve $O\ A\ B$ is a half wave length (and its even and odd harmonics). The numerical values of the harmonics are derived by harmonic analysis.

Representing wave length by λ, initially, for neutral isolated,

$$e' = E_\lambda \cos \frac{2\,\pi\,x}{\lambda} \tag{35}$$

and for neutral grounded

$$e' = E_\lambda \sin \frac{2\,\pi\,x}{\lambda} \tag{35a}$$

where $E\lambda$ is the maximum value of the wave.

The value of p in equation (**34b**) is therefore $\frac{2\,\pi\,x}{\lambda}$ and

$$\omega = \pm \frac{4\,\pi^2\,l^2}{\lambda^2 \sqrt{L\left(\frac{C_g + 4\,\pi^2\,l^2\,C_s}{\lambda^2}\right)}} \tag{35b}$$

$$= \pm \frac{4\,\pi^2\,(l/\lambda)^2}{\sqrt{L\,\{\,C_g + 4\,\pi^2\,C_s\,(l/\lambda)^2\,\}}} \tag{35c}$$

Now l/λ is the ratio of coil length to wave length and we shall designate it by small n., The longest wave to which the winding will oscillate is a quarter wave length, and $n = 1/4$. Thus n may be looked upon as the order of the space harmonic. If n equals one, the wave length equals the coil length; if n equals two, the wave length is one half of the coil length, or, there are two complete wave lengths from line to neutral. Substituting n for l/λ,

$$\omega = \frac{4\,\pi^2\,n^2}{\sqrt{L\,(C_g + 4\,\pi^2\,n^2\,C_s)}} \tag{35d}$$

$$f = \frac{2\,\pi\,n^2}{\sqrt{L\,(C_g + 4\,\pi^2\,n^2\,C_s)}} \tag{35e}$$

For long wave lengths (low harmonics, n small) capacitance to ground predominates,

and
$$f = \frac{2\,\pi\,n^2}{\sqrt{L\ C_g}} \tag{35f}$$

For the very short wave lengths (high order of harmonics, n large) the coil capacitance C_s predominates.

$$f = \frac{n}{\sqrt{L\,C_s}} \tag{35g}$$

Since there are two values of ω, one positive and the other negative, and since $\cos(+\omega)$ equals $\cos(-\omega,)$ equation (33) becomes

$$e' = A\cos(2\,\pi\,n\,x/l)\cos(\omega_n t) + B\cos(2\,\pi\,n\,x/l)\cos(-\omega_n t) \tag{33a}$$

$$= A\cos(2\,\pi\,n\,x/l)\cos\omega_n t + B\cos(2\,\pi\,n\,x/l)\cos\omega_n t \tag{33b}$$

$$= (A+B)\cos(2\,\pi\,n\,x/l)\cos\omega_n t \tag{33c}$$

$$= E_n\cos(2\,\pi\,n\,x/l)\cos\omega_n t \tag{33d}$$

e' is the voltage to the axis of oscillation, and for every harmonic there is a term like (**33d**). The voltage to ground is, for neutral isolated,

$$e = E_0 - E_n\cos(2\,\pi\,n\,x/l)\cos\omega_n t \tag{33e}$$

and for neutral grounded

$$e = E_0\,(x/l) - E_n\sin(2\,\pi\,n\,x/l)\cos\omega_n t \tag{33f}$$

As the voltage oscillates above and below the line of equilibrium, and as the frequency is different for the different waves, we may assume that at some instant the maxima of all the harmonics at a point will add arithmetically, and that will represent the maximum voltage to ground at that point. That is, maximum voltage to ground equals, for neutral isolated.

$$\max e = E_0 + E_n\cos(2\,\pi\,n\,x/l) + \ldots \tag{36a}$$

and for neutral grounded

$$\max e = E_0\,(x/l) + E_n\sin(2\,\pi\,n\,x/l) + \ldots \tag{36b}$$

Of equal importance is the voltage gradient (volts per turn). The maximum voltage gradient at a point occurs when maximum voltage gradients of the various harmonics at that point add directly. This gives, for neutral isolated,

$$\max\frac{d\,e}{d\,x} = (2\,\pi\,n/l)\,E_n\sin(2\,\pi\,n\,x/l) + \ldots \tag{37a}$$

and for neutral grounded

$$\max \frac{d\,e}{d\,x} = E_0/l + (2\,\pi\,n/l)\,E_n \cos\,(2\,\pi\,n\,x/l) + \,.\,. \qquad \textbf{(37b)}$$

It is to be noted that although the higher harmonics may be small in magnitude yet the volts per turn which they produce may not be negligible on account of the volts per turn varying directly with the order of the harmonic. For instance, a tenth harmonic having a magnitude of ten per cent of the fundamental will cause as much strain per turn as the fundamental.

The initial voltage gradient was discussed under equations 14, 15 and 16.

SURGE IMPEDANCE OF A WINDING

The surge impedance of a transformer winding may be defined as the ratio of voltage impressed to current at line end of winding.

By equation (23)

$$\frac{d\,I_L'}{d\,x} = I_0 - \frac{d\,I_s}{d\,x}$$

$$= \frac{C_0\,d\,e}{l\,dt} - l\,C_s\,\frac{d^2\,e}{dxdt}$$

Substituting the general value of e, that is, $e = E \cos p\,x \cos \omega\,t$

$$\frac{d\,I_L}{d\,x} = -\,\omega\,E\,(C_0/l + l\,C_s\,p^2) \cos p\,x \sin \omega\,t$$

and integrating

$$I_L = \frac{\omega\,E}{p}\,(C_0/l + l\,C_s\,p^2) \sin p\,x \sin \omega\,t \qquad \textbf{(38a)}$$

At the line end, $\sin p\,l$ equals one, and the maximum of the current occurs when $\sin w\,t$ equals one.

$$\max I_L = \frac{w\,E}{p}\,(C_0/l + l\,p^2\,C_s) \qquad \textbf{(38b)}$$

$$Z = \frac{E}{I_L} = \frac{p\,l}{\omega\,(C_0 + l^2\,p^2\,C_s)} \qquad \textbf{(39a)}$$

$$Z = \frac{1}{2\,\pi\,n} \times \sqrt{\frac{L}{C_0 + 4\,\pi^2\,n^2\,C_s}} \qquad \textbf{(39b)}$$

It is, therefore, evident that the surge impedance of a winding is not a constant but a function of the wave length, the shorter the wave length the less the surge impedance and hence, for a given voltage the current associated with higher harmonics is greater.

The current surges back and forth into the line, and it is assumed that the surge impedance of the line is low enough not to impede this free oscillation as will be seen in the following example.

EXAMPLE

The constants of the high-voltage winding of the above mentioned transformer are as follows,

$$\begin{aligned} C_g &= 9 \times 10^{-10} \text{ farads} \\ C_s &= 9 \times 10^{-12} \text{ farads} \\ \alpha &= 10 \end{aligned}$$

By formula (**29e**)

$$\begin{array}{rrcl} L = & 8 & \text{for } n = & 1/4 \\ = & 14 & \text{“ } n = & 1/2 \\ = & 20 & \text{“ } n = & 3/4 \\ = & 23 & \text{“ } n = & 1 \\ = & 27 & \text{“ } n = & 5/4 \\ = & 30 & \text{“ } n = & 3/2 \\ = & 32 & \text{“ } n = & 7/4 \\ = & 34 & \text{“ } n = & 4/2 \end{array}$$

The initial voltage distribution is, by equations (**11b**) and (**13b**).

$$\% e = \frac{e}{E_0} = \frac{\cosh (10\, x/l)}{\cosh (10)} \text{ neutral isolated}$$

$$= \frac{\sinh (10\, x/l)}{\sinh (10)} \text{ neutral grounded}$$

These are plotted in Figs 2 and 3 together with curves for other values of α.

Analyzing the curve for $\alpha = 10$ into its space harmonics with respect to the corresponding axis of oscillation, we find the following values:

Neutral Isolated.—

Order of harmonic	Number of wave lengths n	Voltage $\frac{E_n}{E_0}$
Fundamental	1/4	− 125 %
3rd	3/4	+ 34 %
5th	5/4	− 15 %
7th	7/4	+ 7 %
9th	9/4	− 3.5%
11th	11/4	+ 1 %

The frequencies corresponding to these harmonics, calculated by equation (35e), are

Order of harmonics	n	λ	ω	f	Ratio
Fundamental	1/4	168 in.	28,000	4,600	1
3rd	3/4	56 "	150,000	24,000	5.2
5th	5/4	34 "	310,000	49,000	10.6
7th	7/4	24 "	480,000	76,000	16.5

Expressing the voltage to ground in per cent of line voltage (line to ground) the complete equation is

$$\begin{aligned}\%\, e = \frac{e}{E_0} = 1 - 1.25 \cos\left(\frac{\pi}{2} \times \frac{x}{l}\right) \cos\ 28{,}000\, t \\ + 0.34 \cos\left(\frac{3\,\pi}{2} \times \frac{x}{l}\right) \cos 150{,}000\, t \\ - 0.15 \cos\left(\frac{5\,\pi}{2} \times \frac{x}{l}\right) \cos 310{,}000\, t \\ + 0.07 \cos\left(\frac{7\,\pi}{2} \times \frac{x}{l}\right) \cos 480{,}000\, t \text{ etc.}\end{aligned}$$

The maximum possible voltage to ground at any point at any time is equal to

$$\begin{aligned}\text{max. } \%\, e = 1 + 1.25 \cos\left(\frac{\pi}{2} \times \frac{x}{l}\right) \\ + 0.34 \cos\left(\frac{3\,\pi}{2} \times \frac{x}{l}\right)\end{aligned}$$

$$+ 0.15 \cos\left(\frac{5\,\pi}{2} \times \frac{x}{l}\right)$$

$$+ 0.07 \cos\left(\frac{7\,\pi}{2} \times \frac{x}{l}\right) \text{ etc.}$$

This is plotted in Fig. 6.

The maximum voltage gradient is the derivative of the above equation.

$$\text{max. } \%\, e_s = \frac{d\,e}{d\,x} = \frac{\pi}{2\,l} \times 1.25 \sin\left(\frac{\pi\,x}{2\,l}\right)$$

$$+ \frac{3\,\pi}{2\,l} \times 0.34 \sin\left(\frac{3\,\pi\,x}{2\,l}\right)$$

$$+ \frac{5\,\pi}{2\,l} \times 0.15 \sin\left(\frac{5\,\pi\,x}{2\,l}\right)$$

$$+ \frac{7\,\pi}{2\,l} \times 0.07 \sin\left(\frac{7\,\pi\,x}{2\,l}\right) \text{ etc.}$$

This is also plotted in Fig. 6. Calculating the voltage gradient at the line end by this formula we find that it is less than that obtained by equation (**15b**). This means that a sufficient number of harmonics are not included in the above formula. Neglecting the highest harmonics is permissible for the interior of the coil as they may be damped out before the highest possible maximum would be reached, but for the line end it is better to calculate the voltage gradient by the hyperbolic formula. This has been done in the calculation of the above curve.

Neutral Grounded. The initial voltage distribution for this case is practically the same as for isolated neutral (see Fig. 3, $\alpha = 10$). Analyzing this curve into space harmonics with respect to the slant line $\alpha = 0$, we find the following values:

No. of wave lengths on the stack n	$\frac{E_x}{E_0}$	ω	f	Ratio
$\frac{1}{2}$	− .58	84,000	13,000	1
$2 \times \frac{1}{2}$	+ .23	230,000	37,000	2.8
$3 \times \frac{1}{2}$	− .13	390,000	62,000	4.8
$4 \times \frac{1}{2}$	− .06	580,000	92,000	7.1

The maximum voltage to ground is

$$\begin{aligned}\text{max. } \% \, e &= \frac{x}{l} + 0.58 \sin\left(\frac{\pi x}{l}\right) + 0.23 \sin\left(\frac{2\pi x}{l}\right) \\ &\quad + 0.13 \sin\left(\frac{3\pi x}{l}\right) + 0.06 \sin\left(\frac{4\pi x}{l}\right) \text{ etc.}\end{aligned}$$

This is plotted in Fig. 7.

The maximum voltage gradient is the derivative of the above.

$$\begin{aligned}\text{max. } \% \, e_s = \frac{de}{dx} &= \frac{1}{l} + \frac{0.58\pi}{l} \cos\left(\frac{\pi x}{l}\right) \\ &\quad + 0.23 \times \frac{2\pi}{l} \cos\left(\frac{2\pi x}{l}\right) \\ &\quad + 0.13 \times \frac{3\pi}{l} \cos\left(\frac{3\pi x}{l}\right) \\ &\quad + 0.06 \times \frac{4\pi}{l} \cos\left(\frac{4\pi x}{l}\right) \text{ etc.}\end{aligned}$$

This also is plotted in Fig. 7.

Surge Impedance. By equation (**39b**)

n =	1/4	1/2	3/4	1	1 1/4	1 1/2	1 3/4	2
Z =	60,000	38,000	29,000	22,000	17,000	14,000	11,500	9,600

SYMBOLS

α = $\sqrt{C_g/C_s}$

A = Constant of integration

B = Flux density, also constant of integration.

C = Capacitance.

C_g = Capacitance to ground (total.)

C_s = Coil capacitance (total), from line end to neutral.

E_0 = Terminal voltage, *i. e.*, line to ground.

E_n = Max. value of the "n" th harmonic to the axis of oscillation.

e = Voltage to ground at any point at any instant.

e_s = Voltage gradient in the winding, volts per unit length, proportional to volts per turn.

f = Frequency cycles per second, $\omega/2\pi$.

g = Subscript meaning ground.
I = Current.
l = Length of coil (or coil stack), line to neutral.
N = Number of turns total, line to neutral.
n = Number of wave lengths on the winding for a given harmonic.
ω = Angular velocity, radians per second.
$= 2\pi f$
Z = Surge impedance.

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THE GENERAL EQUATIONS OF THE ELECTRIC CIRCUIT—III

Variation of Constants r, L, C, and g, and its Effects

BY CHARLES P. STEINMETZ

Abstract of Paper

In the usual theory of transients the assumption is made, that resistance, inductance, capacity and conductance are constant. This however, is not correct, and as the result thereof, it was not possible to theoretically investigate, and numerically calculate the dissipation of high-frequency disturbances, the flattening of the wave fronts of impulses, the rounding off of steep waves, etc., with the time and the distance of travel, and therefrom to determine the distance, to which the danger from such disturbances extends, and to investigate the conditions of line construction, which limit the danger zone of such phenomena to the smallest local extent.

In the following, two of the foremost causes of change of the line constants with the equivalent frequency are investigated, the unequal current distribution in the conductor, and the electric radiation from the conductor, and shown, that within the range of frequencies which may be met in industrial circuits, the effective resistance of the conductor, and its attenuation constant, may increase more than a million fold.

Equations of the line constants as function of the equivalent frequency are derived, and applications thereof made to a few problems:

(1) The laws of conduction of high-frequency currents, such as produced by lightning discharges and similar disturbances, and the conclusions resulting therefrom on the nature of the conductor.

(2) The decay of high-frequency sine waves in transmission lines.

(3) The attenuation of rectangular waves.

(4) The flattening of the wave front of steep impulses.

It is shown that in high-frequency conduction the section of the conductor is of little importance, but the circumference is the determining factor, except at very high frequencies, where size, shape, and material—within certain limits—becomes of secondary importance. The inductance and the capacity of the conductor remain constant up to very high frequencies, but the effective resistance may increase many thousand fold. At high frequencies, not all the energy consumed by the effective resistance of the conductor is converted into heat, but the major part may be radiated into space and thereby affect other circuits.

The conditions, which cause a flattening of steep wave fronts and impulses, and a rounding of irregular waves, are investigated, and it is shown, that within the range of distances in which

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danger may result from a steep wave front or high frequency, the steepness of the wave front decreases with the square root of the distance traveled by the wave; that size and material of the conductor have little influence, but the distance between conductor and return conductor is the main factor in flattening the wave front and thereby limiting the danger zone.

For convenience, the theoretical part has been separated and placed in an appendix, giving in the text the discussion, with numerous tables derived from the theoretical equations, and curves illustrating these tables.

The investigation is not general, but rather limited to special applications, as the field is too new to permit fargoing generalization.

I.—General

IN 1908, in a paper under the above title, the general equations of the electric circuit were presented and discussed, and in a second paper in 1916, under the title "Outline-of a Theory of Impulse Currents," the application of these general equations to the sepecial cases of direct-current circuits, alternating-current circuits, etc., was discussed, and more particularly a theory of impulse currents outlined, that is, transient currents which are non-periodic in time, and either non-periodic or periodic in space.

In both of these papers however, and in all general theoretical investigations on these subjects, as far as I know, the assumption is made, that the circuit constants; resistance r, inductance L, capacity C and shunted conductance g, are constant. While this is true, with sufficient approximation, for the usual machine frequencies and for moderately high frequencies, experience shows that it is not even approximately true for very high frequencies and for very sudden circuit changes, as steep wave front impulses, etc.

If r, L, C and g are assumed as constant, it follows that the attenuation is independent of the frequency, that is, waves of all frequencies decay at the same rate, and as the result, a complex wave or an impulse traversing a circuit dies out without changing its wave shape or the steepness of its wave front.

Experience, however, has conclusively shown that steep wave fronts are dangerous only near their origin, and rapidly lose their destructiveness by the flattening of the wave front when running along the circuit. Experimentally, small inductances shunted by a spark gap, inserted in transmission lines for testing for high frequencies or steep wave fronts, have shown appreciable spark lengths, that is, high voltage gradients, only near the origin of the disturbance, but no appreciable spark length beyond a few miles from the origin of the disturbance.

The rectangular wave of starting a transmission line by connecting it to a source of voltage, which is given by the theory under the assumption of constant r, L, C and g, and thus shown in most test books, has never been shown in any of the oscillograms of transmission lines, as far as I know.

If r and L are constant, the power factor of the line conductor, $\frac{r}{\sqrt{r^2 + (2\pi fL)}}$, should with increasing frequency continuously decrease, and reach extremely low values, at very high frequencies, so that at these, an oscillatory disturbance should be sustained over very many cycles, and show with increasing frequency an increasing liability to become a sustained or cumulative oscillation. Experience, however, shows that high-frequency oscillations die out much more rapidly than accounted for by the standard theory, and show at very high frequency practically no tendency to become cumulative.

This does not mean that the present theory of transients, which is based on the assumption of constant r, L, C and g, is useless by not correctly representing the actual phenomena, but it means that it correctly represents the transient only in its initial stage and near its origin, but does not satisfactorily represent its course after its initial stage and at some distance from the origin, at least not for high-frequency transients or steep wave fronts.

As the destructive effect of voltage does not depend only on the value of the voltage, but also on the duration of its application, this is a limitation, though not as serious as it may appear, since it tends to understate the danger of high-frequency transients.

However, it makes it impossible to determine such important questions as; how far the danger zone of a high frequency disturbance or steep wave front extends; how the destructiveness decreases with the distance; how it depends on line construction, conductor shape and materials, etc., and to approach the problem of so designing the circuit as to limit the danger from any such disturbance to the smallest local extent.

In the following, therefore, the attempt is made to investigate and calculate theoretically some of the factors, which cause a change of the line constants r, L, C, and g, with increasing frequency or steepness of wave front, and to investigate theoretically the effect produced on the course of the transient as regard to duration and wave shape, by the variation of the line constants.

As this field is rather new, no very general treatment is yet possible, but rather, an outline of the problem, and applications to some of the most important phenomena, such as the conduction of high-frequency currents, the changes of wave shape with time and distance of wave travel, and the flattening of the wave front, and its bearing on circuit construction.

The two most important factors in the variation of the circuit constants r, L, C, and g, seems to be the *unequal current distribution in the conductor* and the *finite velocity of the electric field.*

UNEQUAL CURRENT DISTRIBUTION IN THE CONDUCTOR

The magnetic field of the current surrounds this current and fills all the space outside thereof, up to the return current. Some of the magnetic field due to the current in the interior and in the center of a conductor carrying current, thus is inside of the conductor, while all the magnetic field of the current in the outer layer of the conductor is outside of it. Therefore, more magnetic field surrounds the current in the interior of the conductor than the current in its outer layer, and the inductance therefore increases from the outer layer of the conductor towards its interior, by the "internal magnetic field." In the interior of the conductor the reactance voltage thus is higher than on the outside.

At low frequency, with moderate size of conductor, this difference is inappreciable in its effect. At higher frequencies however, the higher reactance in the interior of the conductor, due to this internal magnetic field, causes the current density to decrease towards the interior of the conductor, and the current to lag, until finally the current flows practically only through a thin layer of the conductor surface.

As the result thereof, the effective resistance of the conductor is increased, due to the uneconomical use of the conductor material caused by the lower current density in the interior, and due to the phase displacement, which results in the sum of the currents in the successive layers of the conductor being larger than the resultant current. Due to this unequal current distribution, the internal reactance of the conductor is decreased, as less current penetrates to the interior of the conductor, and thus produces less magnetic field inside of the conductor.

The derivation of the equations of the effective resistance of unequal current distribution in the conductor, r_1, and of the internal reactance x_1 under these conditions, is given in appendix A. It is interesting to note, that effective resistance and internal reactance, with increasing frequency, approach the same limit, and become proportional to the square root of the frequency, the square root of the permeability, and the square root of the resistivity of the conductor material, while at low frequencies the resistance is independent of the frequency and directly proportional to the resistivity, and the internal reactance is independent of the resistivity and directly proportional to the frequency.

FINITE VELOCITY OF THE ELECTRIC FIELD

In calculating the inductance or the capacity of a conductor, usually the assumption is made, that the electric field is instantaneous, that is, the magnetic field appears and disappears simultaneously with the current, and therefore, is in phase with the current, and the dielectric field appears and disappears simultaneously with the voltage. In reality, however, this is not strictly correct, but the electric field moves with a finite velocity from the conductor outwards. While this velocity is inconceivably high: $S = 3 \times 10^{10}$ cm. per sec., or 300,000 km. per sec., its effect is appreciable at high frequencies. Consider, for instance, a circuit representing average transmission line conditions with 6 ft. = 182 cm., between conductors, traversed by a current of $f = 10^6$, or one million cycles, such as may be produced by a nearby lightning discharge. The wave length of this current and thus of its magnetic field then would be $\frac{S}{f} = \frac{3 \times 10^{10}}{10^6} = 30{,}000$ cm. and the distance of 182 cm. between the line conductors would be $\frac{182}{30{,}000}$ or $\frac{1}{165}$ of a wave length or $\frac{360}{165} = 2.2$ deg. That is, the magnetic field of the current, when it reaches the return conductor, would not be in phase with the current, but $\frac{1}{165}$ of a wave length or 2.2 deg. behind the current. The voltage induced by the magnetic field would not be in quadrature with the current, or wattless, but lag 90 + 2.2 = 92.2 deg. behind the current, thus have an energy component equal to cos 92.2 deg. = 3.8 per cent, giving rise to an effective resistance r_3, equal to 3.8 per cent of the reactance x. Even if at normal frequencies of 60 cycles the reactance is equal only to the ohmic resistance r_0 — usually it is larger—the reactance x to 10^6 cycles would be $\frac{10^6}{60}$, = 16,700 times the ohmic resistance, and the effective resistance of magnetic radiation, r_3, being 3.8 per cent of this reactance, thus would be 630 times the ohmic resistance: $r_3 = 630\, r_0$. Thus, the ohmic resistance would be entirely negligible compared with the effective resistance resulting from the finite velocity of the magnetic field.

Considering however, a high-frequency oscillation of 10^6 cycles, not between the line conductors, but between line conductor and ground, and assume, under average transmission line conditions, 30 ft. as the average height of the conductor above ground. The magnetic field of the conductor then can be represented as that between the conductor and its image conductor, 30 ft. below ground, and the distance between conductor and return conductor would be 2 × 30 ft. = 1820 cm. The lag of the magnetic field, due to the finite velocity of propagation, then becomes 22 deg. thus quite appreciable, and the energy component of the voltage induced by the magnetic field is cos $(90 + 22^0)$ = 37 per cent. This would give rise to an effective or radiation resistance $r_3 = 0.37\, x$. As in this case, the 60-cycle reactance usually is much larger than the ohmic resistance, assuming it as twice would make the radiation resistance $r_3 = 12{,}600\, r_0$, or more than ten thousand times the true ohmic resistance. It is true, that at these high frequencies, the ohmic resistance would be very greatly increased by unequal current distribution in the conductor. But the effective resistance of unequal current distribution increases only proportionally to the square root of the frequency, and, assuming for instance conductor No. 00 B. & S. gage, the effective resistance of unequal current distribution, r_1, would at 10^6 cycles be about 36 times the low frequency ohmic resistance r_0. Thus the effective resistance of magnetic radiation would still be $\frac{12{,}600}{36} = 350$ times the effective resistance of unequal.

current distribution: $r_3 = 350\ r_1$, and the latter, therefore, is negligible compared with the former.

It is interesting to note, that the effective resistance of radiation, r_3, does not represent energy dissipation in the conductor by conversion into heat, but energy dissipation by radiation into space, and in distinction from the "radiation resistance," which dissipates energy into space, the effective resistance of unequal current distribution may be called a "thermal resistance," as it converts electric energy into heat

Thus in this instance of a 10^6-cycle high-frequency discharge between transmission line conductor and ground, the heating of the conductor would be increased 36 fold over that produced by a low-frequency current of the same amperage, by the increase of resistance by unequal current distribution in the conductor; but the total energy dissipation by the conductor would be increased by magnetic radiation still 350 times more, so that the total energy dissipation by the 10^6-cycle current would be 12,600 times greater than it would be with a low-frequency current of the same value, and the attenuation or rate of decay of the current thus would be increased many thousand times, over that calculated on the assumption of constant resistance at all frequencies.

The derivation of the equations of the effective resistance of magnetic radiation, and in general of the effects of the finite velocity of the electric field on the line constants, are given in appendix B.

The magnetic radiation resistance is proportional to the square of the frequency (except at extremely high frequencies). It therefore, is negligible at low and medium frequencies, but becomes the dominating factor at high frequencies. It is proportional to the distance of the return conductor, but entirely independent of size, shape, or material of the conductor, as is to be expected, since it represents the energy dissipated into space. Only at extremely high frequencies, the rise of radiation resistance becomes less than proportional to the square of the frequency. It becomes practically independent of the distance of the return conductor, when the latter becomes of the magnitude of the quarter wave length.

The same applies to the capacity. Due to the finite velocity of propagation, the dielectric or electrostatic field lags behind the voltage which produces it, by the same angle by which the magnetic field lags behind the current, and the capacity current or charging current thus is not in quadrature with the voltage, or reactive, but displaced in phase by more than 90 deg. thus contains a negative energy component, which gives rise to a shunted conductance of dielectric radiation g. This gives rise to an energy dissipation by the conductor, at high frequencies, by dielectric radiation into space, of the same magnitude as the energy dissipation by magnetic radiation, above considered.

The term "shunted conductance" g has been introduced into the general equations of the electric circuit largely from theoretical reasons, as representing the power consumption proportional to the voltage. Most theoretical investigations of transmission circuits consider only r, L and C as the circuit constants, and omit g, since under average transmission line conditions, at low and moderate frequencies, g usually is negligible. In communication circuits, as telegraph and telephone, there is a "leakage," which would be represented by a shunted conductance, and in underground cables there is a considerable energy consumption by dielectric losses in the insulation, as the investigations of the last years have shown, which gives a shunted conductance. In overhead power lines however, energy losses depending on the voltage,—and leading to a term g—have been known only at those high voltages where corona appears. It is interesting therefore to note, that at high frequencies, "shunted conductance" g may reach very formidable values even in transmission lines, due to electrostatic radiation.

In investigating the effect of the finite velocity of the electric field on the inductance L and the capacity C, in appendix B, it is seen, that the equations of external inductance and of capacity are not affected, but remain the same as the usual values derived by neglecting the velocity of the electric field, except at extremely high frequencies, when the distance of the return conductor approaches quarter wave length.

EQUATIONS OF ELECTRICAL CONSTANTS, AND NUMERICAL VALUES

In appendix C are given, compiled from appendices A and B, the equations of the components of the electrical constants, as functions of the frequency, for conductors with return conductor, and also for conductors without return conductor (as approximated by lightning strokes or wireless antennae):

Resistance: true ohmic resistance or effective resistance of unequal current distribution, and magnetic radiation resistance.

Reactance: low frequency internal reactance or internal reactance of unequal current distribution, and external reactance.

Inductance: low frequency internal inductance or internal inductance of unequal current distribution, and external inductance.

Shunted conductance and capacity are not so satisfactorily represented, and therefore, instead of representing energy storage and power dissipation depending on the voltage by a conductance g and a capacity C or susceptance b, in shunt with each other, it is more convenient to represent them by an effective resistance, the dielectric radiation resistance r_c, and a capacity reactance x_c, in series with each other.

As seen from appendix C, four successive stages may be distinguished in the expressions of the circuit constants as function of the frequency.

1. Low frequencies, such as the machine frequencies of 25 and 60 cycles. The resistance is the true ohmic resistance, the internal reactance and inductance that corresponding to uniform current density throughout the conductor, with conductors of moderate size, and of non-magnetic material.

2. Medium frequencies, of the magnitude of a thousand to ten thousand cycles. Resistance and internal reactance or inductance are those due to unequal current distribution in the conductor, that is, the resistance is rapidly increasing, and the internal inductance decreasing. The conductance g is still negligible, radiation effects still absent, and all the energy loss that of thermal resistance.

3. High frequencies, of the magnitude of one hundred thousand to one million cycles. The radiation resistance is appreciable and becomes the dominating factor in the energy dissipation. The internal inductance has practically disappeared, due to the current penetrating only a thin surface layer. A considerable shunted conductance exists due to the dielectric radiation.

4. Extremely high frequencies. Of the magnitude of many millions of cycles, when the quarter wave length has become of the same magnitude or less than the distance of the return conductor. Radiation effects entirely dominate, and the usual expressions of inductance and of capacity have ceased to apply.

This last case is of little industrial importance, as such extremely high frequencies propagate only over short distances.

It would come into consideration only in calculating the flattening of the wave front of a rectangular impulse in the immediate neighborhood of its origin, and similar problems.

Thus far, a general investigation does not seem feasible. Substituting the equations of the circuit constants, as functions of the frequency, into the general equations of the electric circuit, leads to expressions too complex for general utility, and the investigation thus must largely be made by numerical calculations.

Only when the frequencies which are of importance in the problem, lie fairly well in one of the four ranges above discussed —as is the case in the investigation of the flattening of a steep wave front in moderate distances from its origin,—a more general theoretical investigation becomes possible at present.

As instances of industrial importance may be considered in the following:

The conduction of high frequency currents such as produced by lightning and similar disturbances.

The attenuation of waves in overhead transmission circuits.

The rounding of rectangular waves.

The flattening of steep wave fronts.

II.—Lightning Conductors

It has been known for many years that currents of high frequency, very sudden impulses, etc., such as are given by lightning discharges and similar disturbances in electric circuits, do not follow the laws of low-frequency currents. The conduction of such currents however, is of very great industrial importance; in the discharge path of lightning arresters and other protective devices, their ground connections, their connections with the circuit, etc., it is of fundamental importance to design and select the conductor so as to offer minimum impedance to the discharge. Inversely, in the connection of the station to the transmission line, it is of importance to design the conductor for maximum impedance against such currents. The protection of buildings by the lightning rod depends on the design of the conductor system, etc.

However, the high-frequency impedance of the conductor is not the only quantity of importance. At high frequencies, the thermal resistance, which dissipates energy in the conductor by conversion into heat, may be a small part only of the total effective resistance, and the radiation resistance dominates.

That is, most of the power consumed in the conductor is radiated into space. Thus it is not sufficient to merely afford a discharge path for lightning, because while discharging through such path, most of the energy of the lightning may be communicated by radiation to other bodies. This accounts for the power exerted upon bodies near the path of a lightning stroke, the destructive effects of a "side stroke." Hence it is of importance also, to study the extent of the electric field of the high-frequency conductor, to ascertain that nothing is within the electric field, which might be damaged by intercepting the electric field, or may lead the power, communicated to it by the radiation from the discharge path, into other circuits where it may be destructive. Thus a lightning arrester, while functioning perfectly and supposedly giving perfect protection, may be a source of danger, by concentrating the energy of lightning into its discharge path, if this discharge path is carried in close inductive relation to conductors of the circuit which is to be protected.

To show the relative magnitude of the different line constants and their components, in Table I are given their numerical values, in ohms per meter length of conductor, for frequencies from one cycle to one hundred million cycles per second, of a copper wire No. 00 B. & S. gage, for the three conditions:

a. Return conductor at $l' = 6$ ft. $= 182$ cm. corresponding to a discharge between transmission line conductors.

b. With the ground as return conductor, at 30 ft. distance, that is, $l' = 2 \times 30$ ft. $= 1820$ cm. corresponding to a discharge between transmission line and ground.

c. No return conductor, corresponding to the vertical discharge path of a lightning arrester ground, a lightning stroke, etc.

Some of these values are plotted in Fig. 1.

The low frequency values of resistance r_0 and external and internal reactance $x_0 + x_{10}$, have no existence at the higher frequencies. But as they are the values calculated by the usual formulas, they are given in Table I, for comparison with the true effective high-frequency values. The values r_2 and x_2, though given for all frequencies, have a meaning only for the very high frequencies, since at lower frequencies the condition of a conductor without return conductor can hardly be realized, as any conductor within a quarter wave length would act as a more or less effective return conductor.

TABLE I.

CIRCUIT CONSTANTS OF COPPER WIRE NO. 00 B. & S. GAGE PER METER LENGTH OF CONDUCTOR

a. return conductor at 6 ft. = 182 cm. distance.
b. return conductor at 2 × 30 ft. = 1820 cm. distance.
c. no return conductor
conductivity: $\gamma = 6.2 \times 10^5$

		Cycles f =	1	10	10^2	10^3	10^4	10^5	10^6	10^7	10^8
Low Frequency		r_0 =	.000240	.000240	.000240	.000240	.000240	.000240	.000240	.000240	.000240
		x_{10} =	.0000003	.000003	.00003	.0003	.003	.03	.3	3	30
	a.	x_0 =	.0000075	.000075	.00075	.0075	.075	.75	7.5	75	750
	b.		.0000104	.000104	.00104	.0104	.104	1.04	10.4	104	1,040
	a.	z_0 =	.000240	.000252	.000816	.0078	.078	.78	7.8	78	780
	b.		.000240	.000263	.001097	.0107	.107	1.07	10.7	107	1,070
	a.	cos ω_0 =	1.000	.952	.293	.0308	.0031	.00031	.000031	.000003	.0000003
	b.		1.000	.912	.218	.0225	.0022	.00022	.000022	.000002	.0000002
High Frequency		r_1 =	.000240	.000240	.000240	.000273	.000865	.00273	.00865	.0273	.0865
		x_1 =	.0000003	.000003	.000030	.000273	.000865	.00273	.00865	.0273	.0865
	a.	r_2 =	....	....	....	....	.0000048	.00048	.048	4.8	225
	b.		....	....	....	....	.000048	.0048	.48	22.5	194
	c.	r_2 =	.000002	.000020	.000197	.00197	.0197	.197	1.97	19.7	197
	a.	x_2 =	.0000075	.000075	.00075	0.075	.075	.75	7.5	75	490
	b.		.0000104	.000104	.00104	.0104	.104	1.04	10.4	78	505
	c.	x_2 =	.0000285	.000256	.00227	.0198	.169	1.40	11.2	83	515
	a.	z =	.000240	.000252	.000816	.00778	.0759	.753	7.5	75.2	539
	b.		.000240	.000263	.001097	.01068	.1049	1.043	10.4	81.2	541
	c.		.000242	.000367	.00234	.0201	.170	1.42	11.4	85.3	551
	a.	cos ω =	1.000	.952	.293	.0351	.0115	.0043	.0076	.0642	.418
	b.		1.000	.912	.218	.0257	.0087	.0072	.047	.277	.358
	c.		1.000	.710	.186	.112	.121	.141	.173	.232	.358
	a.	$\frac{r_1 + r_2}{r_0}$ =	1.000	1.000	1.000	1.14	3.62	13.4	236	20,100	937,000
	b.		1.000	1.000	1.000	1.14	3.80	31.3	2,030	94,000	808,000
	c.	$\frac{r_1 + r_2}{r_0}$ =	1.008	1.082	1.82	9.35	85.5	832	8,250	82,000	820,000

As seen from the equations, and illustrated in Table I, the thermal resistance of the conductor, r_1, that is, the resistance which converts electrical energy into heat in the conductor, is the true ohmic resistance at low frequencies, but with increasing frequency begins to rise due to unequal current distribution in the conductor (at about 1000 cycles in copper wire No. 00 B. & S. gage) and approaches proportionality with the square root of the frequency, hence reaches values many times the ohmic resistance, at very high frequencies.

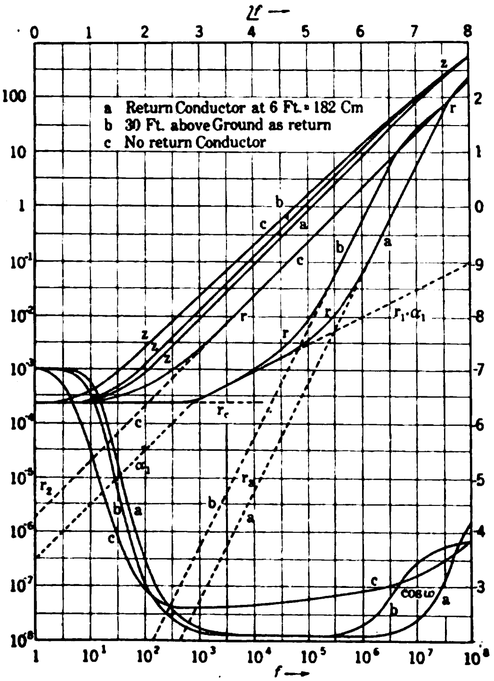

FIG. 1—HIGH FREQUENCY CONSTANTS OF COPPER WIRE NO. 00 B. &. S GAGE

The radiation resistance of the conductor without return conductor, r_2, is proportional to the frequency, but the radiation resistance of the conductor with return conductor, r_3, is proportional to the square of the frequency, hence very small until high frequencies are reached—10,000 to 100,000 cycles. The radiation resistance r_3 of the conductor with return conductor then increases very rapidly and reaches values many thousand times the ohmic resistance. At the very highest frequencies, many millions of cycles, its rate of increase becomes less again, and it approaches proportionality with the first power of the frequency, and approaches the value of radiation resistance r_2, of the conductor without return conductor, at frequencies of a wave length comparable with the distance of the return conductor. The radiation resistance r_3 of the conductor with return conductor is the larger, the greater the distance of the return conductor, and is proportional to this distance, within the range of which it is proportional to the square of the frequency. The radiation resistance of the conductor without return conductor, at the very highest frequencies, is the same as that of the conductor with return conductor, but, being proportional to the frequency, with decreasing frequency, it decreases at a lesser rate, and would even at commercial machine frequencies still be appreciable, if at such frequencies the conditions of a conductor without return conductor could be realized.

The total effective resistance of a conductor under transmission line conditions, that is, with return conductor at finite distance, is at low frequencies constant and is the true ohmic resistance. With increasing frequency, it begins to increase first slowly—at about 1000 cycles under transmission line conditions—and approaches proportionality to the square root of the frequency, as the result of the screening effect of the unequal current distribution in the conductor. Then the increase becomes more rapid, due to the appearance of the radiation resistance—at about 100,000 cycles under transmission line conditions—and reaches proportionality with the square of the frequency, at values many thousand times the ohmic resistance. Finally, at the very highest frequencies—10 million cycles—the rate of increase becomes less again, and approaches proportionality with the frequency.

It is interesting to note that the external reactance of the conductor with return conductor, or radiation reactance x_3, has up to very high frequencies, millions of cycles, the same value x_0 as calculated by the low frequency formula, that is, by neglecting the finite velocity of the field, hence is proportional to the frequency. The internal reactance $x_1 = x_{10}$, and is proportional to the frequency at low frequencies, but drops behind x_{10} due to unequal current distribution in the conductor, and approaches proportionality with the square root of the frequency. As, however, the internal reactance in a small part of the total reactance, it follows, that the total reactance of the conductor and thus also the absolute value of the impedance (for all higher frequencies, where the reactance preponderates) can be calculated by the usual low frequency reactance formula, which neglects the finite velocity of the field. Hence, the inductance L of the conductor can be assumed as approximately constant for all frequencies up to millions of cycles; it decreases only very slowly by the decreasing internal reactance of unequal current distribution. Only at the very highest frequencies, where the wave length is comparable with the distance of the return conductor, the inductance L decreases, and the reactance $x_1 + x_3$ increases less then proportional to the frequency.

In a conductor without return conductor, the reactance at the very highest frequencies is approximately the same as in a conductor with return conductor. With decreasing frequency, however, $x_1 + x_2$ decreases less then proportional to the frequency, that is, the inductance L increases—and becomes infinity for zero frequency, if such were possible.

Without considering unequal current distribution in the conductor and the finite velocity of the electric field, the power factor cos ω would steadily decrease, from unity at very low frequencies, to zero at infinite frequency. Due to the increase of the effective resistance, the power factor cos ω first decreases, from unity at low frequency, down to a minimum at some high frequency, and then increases again to high values at very high frequencies. The minimum value of the power factor is the lower and occurs at the higher frequencies, the shorter the distance of the return conductor is. Thus with the return conductor at 6 ft. distance, the power factor is 0.43 per cent at 100,000 cycles; with the return conductor at 60 ft. distance, it is 0.72 per cent; in the conductor without return conductor the power factor is 11.2 per cent at 1000 cycles.

It is of interest to determine the effect of size, shape and material on the high-frequency constants of a conductor.

These high-frequency constants are, per unit length of conductor:

Internal constants:

Thermal resistance and internal reactance:

$$r_1 = x_1 = \frac{\pi}{l_1} \sqrt{\frac{0.4 \, \mu f}{\gamma}} \, 10^{-4} \text{ ohms per cm.} \qquad (8) \; (9)$$

External constants:
Radiation resistance:

$$r_3 = \frac{8\pi^2 f^2 l'}{S} 10^{-9} \text{ ohms per cm.} \qquad \textbf{(16)}$$

External reactance:

$$x_3 = 4\pi f \log \frac{2\pi l'}{l_2} 10^{-9} \text{ ohms per cm.} \qquad \textbf{(19)}$$

These approximations hold for all but the very highest, and very low frequencies, that is, are correct within the frequency range with lower limit of about 1000 cycles, and upper limit of about 10 million cycles. Thus they apply for all those high frequencies which are of importance in the disturbances occuring in industrial circuits with the exception of the lowest harmonics of low frequency surges.

The constants of the conductor material enter the equations only as the ratio $\frac{\mu}{\gamma}$, permeability to conductivity, in the internal constants r_1 and x_1. Thus higher permeability has the same effect in increasing the thermal resistance as lower conductivity, and for instance, a cast silicon rod of permeability $\mu = 1$, and conductivity $\gamma = 55$, has the same high-frequency resistance and reactance, as an iron rod of the same size, of wrought iron, of permeability $\mu = 2{,}000$ and conductivity $\gamma = 1.1 \times 10^5$, that is, of the same $\frac{\mu}{\gamma} = 0.0182$, though the latter has 2000 times the conductivity of the former.

Provided however, that size of conductor and frequency are such as to fulfill the conditions under which equations (**8**) and (**9**) are applicable, which is, that the conductor is large compared with the depth of penetration of the current into the conductor:

$$l_p = \frac{10^4}{\pi \sqrt{0.4 \ \gamma \mu f}}$$

Thus an iron rod of two inches (five cm.) diameter has at one million cycles the same thermal resistance as a silicon rod of the same size: 0.17 ohms per meter, since the depth of penetration is $l_p = 0.00034$ cm. for iron, 0.68 cm. for silicon, thus in either case small compared with radius of the conductor $l_r = 2.5$ cm.

At 10,000 cycles, however, the iron rod has the thermal resistance and internal reactance $r_1 = x_1 = 0.017$ ohms per meter, the penetration being $l_p = 0.0034$ cm. thus small. For the silicon rod, however, at 10,000 cycles the penetration if $l_p = 6.8$ cm. thus at the radius $l_r = 2.5$ cm. formulas (8) and (9) do not apply any more, but it is approximately (that is neglecting unequal current distribution): $r_1 = 0.093$ ohms per meter, or 5.5 times the resistance of the iron rod, while the internal reactance is $x_1 = 0.031$ ohms per meter, hence 80 per cent higher than that of the iron rod of the same size.

In the equations of the external constants, the radiation resistance and reactance, the material constants of the conductor do not enter, and the radiation resistance and the external reactance thus are independent of the conductor material.

The dimensional constants of the conductor, size and shape, enter the equation only as the circumference of the conductor l_1, l_2, that is, only the circumference of the conductor counts in high-frequency conduction, and all conductors of the same material, regardless of size and shape, have the same high-frequency resistances and reactances as long as they have the same conductor circumference. Thus a solid copper rod or a thin copper cylinder of the same outer diameter as the rod, or a flat copper ribbon of a circumference equal to that of the rod, are equally good high-frequency conductors, though the hollow cylinder or the ribbon may contain only a small part of the material contained in the solid copper rod. Provided, however, that the thickness or depth of the conductor,(the thickness of wall of the hollow cylinder, half the thickness of the copper ribbon) is larger than the depth of penetration of current into the conductor, which is

$$l_p = \frac{10^4}{\pi \sqrt{0.4 \gamma \mu}}$$

In the expression of the radiation resistance, r_3, neither the material nor the dimensions of the conductor enter, that is,the radiation resistance of a conductor is independent of size, shape or material of the conductor and depends only on frequency and distance of the return conductor.

Thus a thin steel wire or a wet string have the same radiation resistance as a large copper bar. Obviously, the thermal resistance of the former is much larger and the total effective resistance thus would be larger except at those very high frequencies, at which the radiation resistance dominates.

As illustration may be calculated, for frequencies from 10 thousand to 10 million cycles and for 60 cycles, the resistances and reactances and thus the total impedance, the power factor, the voltage drop per meter at 100 amperes, of various conductors, for the three conditions:

a. High frequency between conductors 6 ft. apart:

$$l' = 182 \text{ cm.}$$

b. High frequency between conductor and ground 30 ft. below conductor:

$$l' = 1820 \text{ cm.}$$

c. High frequency discharge through vertical conductor without return conductor:

$$l' = \infty$$

For the conductors:

(1) Copper wire No. 00 B. & S. gage

$l_r = 0.463$ cm. $\gamma = 6.2 \times 10^5$

(2) Iron wire of the same size as (1):

$\mu = 2{,}000$ $\gamma = 1.1 \times 10^5$

(3) Copper ribbon of thickness equal to twice the depth of penetration at 10,000 cycles, and the same amount of material as (1), that is, 0.128 cm. by 5.52 cm.

(4) Iron ribbon of the same size as (3).

(5) Two-inch iron pipe, ⅛ inch thick,

This gives the depth of penetration at $f = 10^4$ cycles:

$$\text{for copper; } l_p = \frac{6.4}{\sqrt{f}} = 0.064 \text{ cm.}$$

$$\text{for iron: } l_p = \frac{0.34}{\sqrt{f}} = 0.0034 \text{ cm.}$$

Table II gives the values of $r_0, x_0, r_1, r_3, r_2, x_1, x_3, x_2, r_1 + r_3, r_1 + r_2, x_1 + x_3, x_1 + x_2, z, \cos \omega, e$ and l_p, for $f = 10^6$ cycles.

Table III gives the values of $r_1 + r_3$, or $r_1 + r_2$, z, $\cos \omega$ and e, for $f = 60, 10^4, 10^5, 10^6, 10^7$ cycles for the five kinds of conductors.

It is interesting to compare in Table III, the constants of the first four conductors, as they have the same section, representing about average section of transmission conductors, but represent two shapes, round wire and thin flat ribbon, and two kinds of material, copper—high conductivity and non-magnetic,—and iron—magnetic material of medium conductivity.

As seen, the effect of conductor shape and conductor ma-

TABLE II.

CIRCUIT CONSTANTS FOR $f = 10^6$ = ONE MILLION CYCLES PER METER LENGTH OF CONDUCTOR.

a. return conductor at 6 ft. = 182 cm. distance.
b. return conductor at 2 × 30 ft. = 1820 cm. distance.
c. no return conductor

		(1) Copper wire:	(2) Iron wire:	(3) Copper ribbon:	(4) Iron ribbon:	(5) Iron pipe:	
$r_0 = \frac{100}{A\ \gamma} =$		0.00024	0.00135	0.00024	0.00135	0.000197	
$x_0 = 0.4\ \pi\ f\left(\log\frac{2\ \pi f l'}{l_2} + \frac{l_0}{l_2}\ \frac{\mu}{4}\right)10^{-6} =$	a.	7.8	635	3.05	173	81	ohms
	b.	10.8	638	5.95	176	84	"
$r_1 = \frac{100\ \pi}{l_1}\sqrt{\frac{0.4\ \mu f}{\gamma}}\ 10^{-4} =$		0.00865	0.92	0.00233	0.248	0.167	"
$r_3 = \frac{0.8\ \pi^2 f^2 l^1}{S}\ 10^{-6} =$	a.	0.048	0.048	0.048	0.048	0.048	"
	b.	0.48	0.48	0.48	0.48	0.48	"
$r_2 = 0.2\ \pi^2 f\ 10^{-6} =$	c.	1.97	1.97	1.97	1.97	1.97	"
$x_1 = \frac{100\ \pi}{l_1}\sqrt{\frac{0.4\ \mu f}{\gamma}}\ 10^{-4} =$		0.00865	0.92	0.00233	0.248	0.167	"
$x_3 = 0.4\pi f \log\frac{2\ \pi f l'}{l_2}\ 10^{-6} =$	a.	7.5	7.5	2.97	2.97	2.47	"
	b.	10.4	10.4	5.87	5.87	5.37	"
$x_2 = 0.4\ \pi f\left(\log\frac{S}{l_2 f} - 0.5772\right)10^{-6} =$	c.	11.2	11.2	9.5	9.5	8.9	"
$r = r_1 + r_3 =$	a.	0.0567	0.97	0.0503	0.296	0.215	ohms
	b.	0.489	1.40	0.482	0.728	0.647	"
$r = r_1 + r_2 =$	c.	1.98	2.89	1.97	2.22	2.14	"
$x = x_1 + x_3 =$	a.	7.5	8.42	2.97	3.22	2.64	"
	b.	10.4	11.32	5.87	6.12	5.54	"
$x = x_1 + x_2 =$	c.	11.2	12.12	9.50	9.75	9.07	"
$z = \sqrt{r^2 + x^2} =$	a.	7.5	8.46	2.97	3.23	2.65	"
	b.	10.4	11.4	5.89	6.16	5.58	"
	c.	11.4	12.45	9.7	10.0	9.3	"
$\cos\omega = \frac{r}{z} =$	a.	0.76	11.5	1.7	9.2	8.1	per cent
	b.	4.7	12.3	8.2	11.8	11.6	"
	c.	17.3	23.3	20.3	22.2	23.0	"
$e = 100\ z =$	a.	750	846	296	323	265	volts
	b.	1040	1140	589	616	558	"
	c.	1140	1245	970	1000	930	"
$l_p = \frac{10^4}{\pi\sqrt{0.4\ \gamma\ \mu f}} =$		0.0064	0.00034	0.0064	0.00034	0.00034	cm.

TABLE III.

	Conductors 6 ft. apart:					Conductor 30 ft. above Ground:					Conductor without return conductor:				
Frequency, cycles:	60	10^4	10^5	10^6	10^7	60	10^4	10^5	10^6	10^7	60	10^4	10^5	10^6	10^7
Resistance, r_1 in ohms per meter:															
1. Copper wire	0.00024	0.00087	0.0052	0.0567	4.827	0.00024	0.00091	0.0075	0.489	22.5	....	0.0206	.200	1.98	19.7
2. Iron wire	0.0072	0.092	0.292	0.97	7.72	0.0072	0.092	0.297	1.40	25.4	....	0.112	.489	2.89	20.0
3. Copper ribbon	0.00024	0.00024	0.00122	0.0503	4.81	0.00024	0.00028	0.0055	0.482	22.5	....	0.0199	.198	1.97	19.7
4. Iron ribbon	0.0019	0.0248	0.079	0.296	5.58	0.0019	0.0248	0.083	0.728	23.3	....	0.0435	.265	2.22	20.5
5. Iron pipe	0.0013	0.0167	0.053	0.215	5.33	0.0013	0.0167	0.058	0.647	23.0	....	0.0364	.250	2.14	20.2
Impedance, z, in ohms per meter.															
1. Copper wire	0.00053	0.076	0.753	7.51	75	0.00069	0.105	1.043	10.41	81	....	0.115	1.14	11.4	85
2. Iron wire	0.0105	0.191	1.083	8.46	78	0.0106	0.218	1.37	11.4	85	....	0.233	1.49	12.45	88
3. Copper ribbon	0.00030	0.030	0.298	2.97	30	0.00043	0.059	0.588	5.89	49	....	0.097	0.97	9.7	72
4. Iron ribbon	0.0028	0.060	0.315	3.23	31	0.0030	0.087	0.67	6.16	51	....	0.127	1.06	10.0	74
5. Iron pipe	0.00195	0.0446	0.305	2.65	26	0.0021	0.072	0.592	5.58	47	....	0.112	0.97	9.3	70
Power Factor cos ω, in per cent:															
1. Copper wire	45.3	1.14	0.69	0.76	6.4	34.8	0.87	0.72	4.7	27.8	....	17.9	17.5	17.3	23.2
2. Iron wire	69.5	48.2	27.0	11.5	9.9	68.0	42.2	21.6	12.3	30.0	....	48.0	32.7	23.3	22.7
3. Copper ribbon	80.0	0.8	0.41	1.7	16.0	53.5	0.48	0.93	8.2	46.0	....	20.5	20.4	20.3	27.3
4. Iron ribbon	68.0	41.3	25.1	9.2	18.0	63.3	28.6	12.4	11.8	45.8	....	34.3	25.0	22.2	27.7
5. Iron pipe	66.7	37.5	17.4	8.1	20.4	62.0	23.2	9.8	11.6	49.0	....	32.5	25.8	23.0	29.0
Voltage, e, in volts per meter															
1. Copper wire	0.053	7.6	75	751	7500	0.069	10.5	104	1041	8100	....	11.5	114	1140	8500
2. Iron wire	1.05	19.1	108	846	7800	1.06	21.8	137	1140	8500	....	23.3	149	1245	8800
3. Copper ribbon	0.03	3.0	30	297	3000	0.043	5.9	59	589	4900	....	9.7	97	970	7200
4. Iron ribbon	0.28	6	36	323	3100	0.30	8.7	67	616	5100	....	12.7	106	1000	7400
5. Iron pipe	0.195	4.5	30	265	2600	0.21	7.2	59	558	4700	....	11.2	97	930	7000

terial is very great at machine frequencies, 60 cycles, but becomes small and almost negligible at extremely high frequencies. This is rather against the usual assumption.

The reason is that at machine frequencies, the unequal current distribution, or the screening effect of the internal magnetic field, is still practically absent in copper conductors, even in round wires of medium size, while it is practically complete in iron conductors, even in ribbon of $^1/_{20}$-inch thickness; while at very high frequencies the effect of radiation preponderates, which is independent of the material, and the radiation resistance even independent of the shape of the conductor.

Thus under transmission line conditions, first and second section of Table III, at 60 cycles the impedance, and hence the voltage drop in the iron conductor is from 7 to 20 times that of the copper conductor; at 10,000 cycles the voltage drop in the iron conductor is only from 1.5 to 2.5 times that in the copper conductor; the difference has decreased to from 14 per cent to 44 per cent at 100,000 cycles, 5 per cent to 12.5 per cent at one million cycles, while at 10 million cycles the voltage drop in the iron conductor is only 3 to 5 per cent higher, thus practically the same and the only difference is that due to the conductor shape.

The effective resistance, and thus the power consumption in the iron conductor at 60 cycles is from 8 to 30 times that of the copper conductor, but with increasing frequency the difference in the effective resistance increases to from 88 to 106 times at 10,000 cycles, reaches a maximum, and then decreases again, and is from 15 to 65 times that of the copper conductor at 100,000 cycles, only 1½ to 17 times at a million cycles, while at 10 million cycles and above, all the differences in the effective resistance practically disappear.

As the result, the power factor of the conductor,—being the same, 100 per cent, at extremely low frequency and not much different, and fairly high at machine frequency—decreases with increasing frequency, reaches a minimum and then increases again to considerable values at extremely high frequency,—where the high radiation resistance comes into play. The difference between iron and copper, however, is that the minimum value of the power factor, at medium high frequencies, is very low in copper, a fraction of one per cent, while in the iron conductor the power factor always retains considerable values, the minimum being 10 or more times that of the copper conductor. Thus an oscillation in an iron conductor must die out at a much faster rate then in a copper conductor and the liability of the formation of a continual or cumulative oscillation may exist in copper conductors but hardly in iron conductors.

The effect of the shape of the conductor on the impedance or voltage drop is fairly uniform throughout the entire frequency range, the voltage drop being the smaller, the larger the circumference.

With regards to the effective resistance, however, the effect of the conductor shape is considerable at very low frequencies in iron conductors, but absent with copper conductors, due to the absence of the screening effect in copper at low frequency. With increasing frequency, the difference appears in the effective resistance of the copper conductor also, with the appearance of unequal current distribution, and the ratio of the resistance of the round conductor to that of the flat conductor approaches the same value in copper as in iron. With the approach of very high frequency, however, the difference decreases again, with the appearance of radiation effect, and finally vanishes.

Thus to convey currents of extremely high frequency, an iron conductor is almost as good as a copper conductor of the same shape and cross section. As iron is very much cheaper than copper, it follows that in high frequency conduction an iron conductor under the conditions of Table III should be better than a copper conductor of the same cost and the same general shape, due to the larger size or rather circumference of the iron conductor.

There is, however, a material advantage at extremely high frequencies as well as at moderately high frequencies, in lower voltage drop at the same current resulting from such a shape conductor as gives maximum circumference, such as ribbon or hollow conductor. This advantage of ribbon or hollow tube, over the solid round conductor, exists also in the resistance and thus power consumption at medium high frequencies, but not at extremely high frequencies, but at the latter, in power consumption all conductors, regardless of size, shape or material, are practically equal.

With the thickness of ribbon conductor considered in Table III, of about $^1/_{20}$ inch, which is about the smallest mechanically permissible under usual conditions, the screening effect even in copper conductors is practically complete at 10,000 cycles, that is, the depth of penetration less than one half the thickness of the conductor. It follows, that in the design of high-frequency conductor, the thickness of the ribbon or hollow cylinder is essentially determined by mechanical and not by electrical considerations; in other words, the thinnest mechanically permissible conductor usually is thicker than necessary for carrying the current. As iron usually cannot be employed in as thin ribbon as copper, due to its rusting, an iron conductor would have a larger section than a copper conductor of the same voltage drop and power consumption. Thereby a part of the advantage gained by the employment of the cheaper material would be lost.

The last section of Table III gives the constants of the conductor without return conductor, such as would be represented by the discharge circuit of a lightning arrester, by a wireless telegraph antenna, etc., while the first two sections correspond to transmission line conditions; high frequency currents between line conductors and between line and ground.

In the third section of Table III, the 60-cycle values are not given, and the values given for the lower high-frequencies, 10^4 and even 10^5 cycles, usually have little meaning, are rarely realizable; they would correspond to a vertical conductor, as lightning arrester ground circuit, under conditions where no other conductor is within quarter wave distance. Even at 10^5 cycles, however, the quarter wave length is still 750 m. Thus there will practically always be other conductors within the field of the discharge conductor, acting as a partial return conductor, and the actual values of impedance and resistance, that is, of voltage drop and power consumption in the conductor, thus will be intermediate between those given in the third section, for a conductor without return conductor, and those given in the first sections, for conductors with return conductors. Except at extremely high frequencies, at which the wave length gets so short that the condition of a conductor without return conductor becomes realizable. It is interesting to note, therefore, that at extremely high frequencies, the constants of the conductor without return conductor approach those of the conductor with return conductor. At lower high frequencies, impedance and resistance, and thus voltage drop and power consumption, of the returnless conductor are much higher than those of the conductor with return, the more so the lower the frequency.

However, while the case of the conductor without return conductor is not realizable at low and medium high frequencies in industrial circuits, it probably is more or less realized by the lightning discharge between ground and cloud, and the constants given in the third section of Table III would probably approximately represent the conditions met in the conductors of lightning rods such as used for the protection of buildings against lightning.

It is interesting to note that with such a conductor without return conductor, the power factor is always fairly high, even with copper as conductor material. The impedance and thus the voltage drop does not differ much from those of the conductor with return conductor. The resistance, however, and thus the power consumption are much higher, sometimes, in copper conductors, more than a thousand times as large, showing the large amount of energy radiated by the conductor—which reappears more or less destructively as "induced lightning stroke" in objects in the neighborhood of the lightning stroke.

III.—Wave Decay in Transmission Lines

From the equations given in Appendix C, numerical values of the line constants are calculated and given in Table IV, for average transmission line conditions, that is, a copper wire, No. 00, with 6 ft. = 182 cm. between the conductors, and an average height of 30 ft. = 910 cm. above ground, for the two conditions:

a. a high frequency oscillation between two line conductors;

b. a high frequency oscillation between one line conductor and the ground.

The table gives:

the thermal resistance r_1, the radiation resistance r_3, and the total resistance $r = r_1 + r_3$;

the internal reactance x_1, the external reactance x_3 and the total reactance $x = x_1 + x_3$.

the magnetic attenuation $u_1 = \frac{r}{2L}$, the dielectric attenuation $u_2 = \frac{g}{2C}$, and the total attenuation $u = u_1 + u_2$.

The table also gives the duration of a transient in microseconds t, and in cycles N, that is, the time which a high fre-

TABLE IV.

ATTENUATION CONSTANTS OF COPPER WIRE NO. 00 B. & S. GAGE.

per kilometer of conductor

f =	25	60	500	750	1,000	2,000	5,000	7,500	10,000	15,000	20,000	50,000	75,000	10^5	2×10^5	5×10	7.5×10^5	10^6	2×10^6	5×10^6	Cycles
$\underline{/f}$ =	1.398	1.778	2.699	2.875	3	3.301	3.699	3.875	4	4.176	4.301	4.699	4.875	5	5.301	5.699	5.875	6	6.301	6.699	
r_1 =	.24	.24	.24	.24	.273	.386	.612	.750	.865	1.060	1.225	1.93	2.37	2.73	3.86	6.12	7.50	8.65	12.25	19.3	ohms
x_1 =	.008	.019	.157	.236	.273	.386	.612	.750	.865	1.060	1.225	1.93	2.37	2.73	3.86	6.12	7.50	8.65	12.25	19.3	"
a. return conductor at 6 ft. = 182 cm. distance.																					
r_2 =	......	......	......	......	......	......	.0012	.0027	.0048	.0108	.0192	.12	.27	.48	1.92	12	27	48	192	1,200	"
r =	.24	.24	.24	.24	.273	.386	.613	.753	.870	1.071	1.243	2.05	2.64	3.21	5.78	18.1	34.5	56.6	204	1,219	"
x_2 =	.187	.45	3.75	5.625	7.5	15	37.5	56.25	75	112.5	150	375	562.5	750	1,500	3,750	5,625	7,500	15,000	37,500	"
x =	.195	.469	3.907	5.861	7.773	15.39	38.11	57.0	75.86	113.6	151.2	376.9	564.9	752.7	1,504	3,756 9	5,632	7,509	15,012	37,520	"
L =	1.245	1.245	1.245	1.245	1.24	1.23	1.22	1.215	1.21	1.205	1.205	1.20	1.20	1.20	1.20	1.15	1.195	1.195	1.195	1.195	henrys
$u_1 = \frac{r}{2L}$ =	96	96	96	96	110	157	251	310	360	445	516	855	1,100	1,340	2,410	7,570	14,400	23,700	85,600	510,000	
$u_2 = \frac{g}{2C}$ =	......	......	.005	.011	.020	.080	.5	1.125	2.0	4.5	8.0	50	112.5	200	800	5,000	11,200	20,000	80,000	500,000	
$u = u_1 + u_2$ =	96	96	96	96	110	157	252	311	362	450	524	905	1,212	1,540	3,210	12,570	25,650	43,700	165,600	1,010,000	
$\underline{/u}$ =	1.982	1.982	1.982	1.982	2.041	2.196	2.401	2.493	2.559	2.653	2.719	2.957	3.084	3.187	3.506	4.099	4.409	4.640	5.219	6.004	
t =	10,400	10,400	10,400	10,400	9,090	6,370	3,970	3,210	2,760	2,220	1,910	1,100	825	649	311	79.6	39.0	22.9	6.04	1.00	micro-seconds
N =	.26	.62	5.2	7.8	9.09	12.74	19.85	24.1	27.6	33.3	38.2	55.0	61.9	64.9	62.2	39.8	29.2	22.9	12.1	5.0	cycles
cos ω =	......	......	6.16	4.10	3.51	2.52	1.61	1.32	1.15	.94	.82	.54	.47	.43	.38	.48	.61	.75	1.36	3.25	per cent
cos ω_c =	......	......	......	......	......	......	......	......	.01	.01	.01	.03	.05	.06	.13	.32	.48	.64	1.27	3.18	per cent
b. conductor 30 ft. above ground as return: l' = 1820 cm.																					
r_2 =	......	......	......	......	......	......	.012	.027	.048	.108	.192	1.2	2.7	4.8	19.2	120	270	480	1,920	12,000	ohms
r =	.24	.24	.24	.24	.273	.386	.624	.777	.913	1.168	1.417	3.13	5.07	7.53	23.06	126.1	277.5	488.6	1,932	12,020	"
x_2 =	.26	.624	5.2	7.8	10.4	20.8	52	78	104	156	208	520	780	1,040	2,080	5,200	7,800	10,400	20,800	52,000	"
x =	.268	.643	5.357	8.036	10.67	21.16	52.61	78.75	104.9	157.1	209.2	252	782	1,043	2,084	5,206	7,807	10,409	20,812	52,020	"
L =	1.705	1.705	1.705	1.705	1.70	1.69	1.68	1.675	1.69	1.665	1.665	1.66	1.66	1.66	1.66	1.655	1.655	1.655	1.655	1.655	henrys
$u_1 = \frac{r}{2L}$ =	70	70	70	70	80	114	186	232	273	350	424	942	1,520	2,270	6,930	38,200	83,800	147,500	583,000	3,630,000	
$u_2 = \frac{g}{2C}$ =	......	......	.04	.08	.14	.58	3.6	8.1	14.4	32.5	57.6	360	810	1,440	5,760	36,000	81,000	144,000	576,000	3,600,000	
$u = u_1 + u_2$ =	70	70	70	70	80	115	190	240	287	383	482	1,302	2,330	3,710	12,690	74,200	164,800	291,500	1,159,000	7,230,000	
$\underline{/u}$ =	1.845	1.845	1.845	1.845	1.903	2.061	2.279	2.380	2.458	2.583	2.683	3.115	3.367	3.569	4.103	4.870	5.217	5.465	6.064	6.859	
t =	14,300	14,300	14,300	14,300	12,500	8,700	5,260	4,170	3,480	2,610	2,070	768	429	269	78.8	13.5	6.07	3.43	.86	.14	micro-seconds
N =	.36	.86	7.15	10.7	12.5	17.4	26.3	31.3	34.8	39.1	41.4	38.4	31.2	26.9	15.8	6.75	4.55	3.43	1.72	.69	cycles
cos ω =	......	......	4.48	2.98	2.56	1.83	1.19	.98	.87	.74	.68	.60	.65	.71	1.10	2.42	3.55	4.70	9.24	22.5	per cent
cos ω_c =	......	......	......	......	......	.01	.02	.03	.05	.07	.09	.23	.35	.46	.92	2.31	3.46	4.62	9.22	22.5	per cent

quency oscillation of the frequency f would last, if continuing with its initial intensity, and the number of cycles, which it would perform. It also gives the power factor, in per cent, of the series circuit, as determined by resistance and inductance, and of the shunt circuit, as determined by shunted conductance and capacity.

As seen, the attenuation constant u is constant up to nearly one thousand cycles. Thus in this range, all the frequencies die out at the same rate. From about one thousand cycles up to about 100,000 cycles, the attenuation constant gradually increases, and thus oscillations die out the more rapidly, the higher the frequency, as seen by the gradual decrease of the duration t. However, as the increase of the attenuation constant and thus the increase of the rapidity of the decay of the disturbance, in this range, is smaller than the increase of frequency, the number of cycles performed by the oscillation increases. Thus, at 25 or 60 cycles, the stored energy,which supplies the oscillating power, would be expended in less than one cycle, that is, a real oscillation would hardly materialize (except by other sources of energy, as the stored magnetic energy of a transformer connected to the line). At 1000 cycles, the oscillation would last 9 to 12 cycles, and at still higher frequencies reach a maximum of 41.4 cycles at 20,000 cycles frequency, in the oscillation against ground; 64.9 cycles at 100,000 cycles, in the oscillation between line conductors. This represents a fairly well sustained oscillation, in which the cumulative effect of successive cycles may be considerable. Above 100,000 cycles the attenuation constant begins to rise rapidly, and reaches enormous values, due to the rapidly increasing energy dissipation by radiation. As the result, the duration of the oscillation very rapidly decreases, and the number of cycles performed by the oscillation decreases, until, beyond a million cycles, the energy dissipation is so rapid, that practically no oscillation can occur; the oscillation dying out in a cycle or less, thus being practically harmless.

The attenuation constant is plotted, up to 15,000 cycles, in Fig. 2, with the frequency as abscissas, and is plotted in Fig. 3 in logarithmic scale, as (3).

Noteworthy is the great difference between the oscillation against ground, and the oscillation between line conductors. The oscillation against ground is more persistent at low frequencies, due to the greater amount of stored energy in the electric field of the conductor, which reaches all the distance to the ground. When reaching into very high frequencies however, the energy dissipation by radiation becomes appreciable at lower frequencies in the oscillation against ground, than in the oscillation between line conductors, and reaches much higher values, with the result that the decay of an oscillation between line and ground is much more rapid at high frequencies than the decay of an oscillation between line conductors. For instance, at 100,000 cycles, the latter performs 65 cycles before dying out, while the former has dissipated its energy in 27 cycles, that is, in less than half the time.

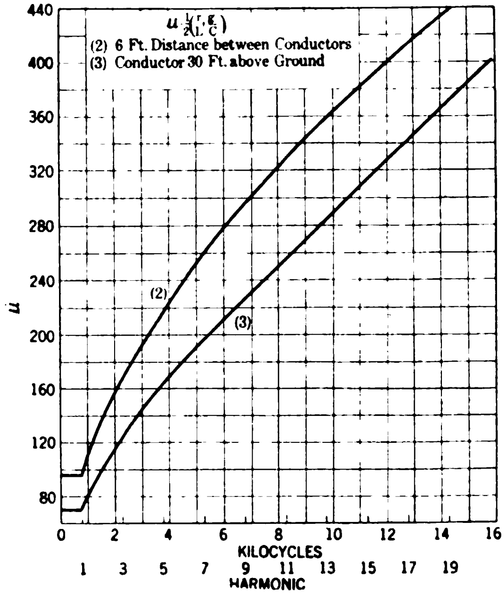

FIG. 2—ATTENUATION CONSTANT OF WIRE NO. 00 B. & S. GAGE COPPER
$U = 1/2 \, (r/L + g/C)$

To further investigate this, in Tables V and VI the numerical values of effective resistance, power factor, attenuation constant and duration of a transient oscillation, in cycles, are given for six typical conductors and circuits, for frequencies from 10 cycles to five million cycles, and plotted in figures 3, 4, and 5, in logarithmic scale.

1, 2, and 3 are lines of high power: copper conductor No. 00 B. & S. gage, in 1 with 18 inches = 45.5 cm. between conductors, corresponding about to average distribution conductors, in 2 with 6 ft. = 182 cm., between conductors, corresponding to about average transmission line conductors with the oscillation between two lines, and in 3 with 60 ft. = 1830 cm. between conductor and return conductor, corresponding to an oscillation between line and ground, under average transmission line conditions, with the conductor 30 ft. above ground. 4, 5 and 6 give the same condition of an oscillation between line and ground, but in 4 an iron wire of the size of No. 00 B. & S. gage, such as has been proposed for the station end of transmission lines, to oppose the approach of high frequency disturbances. In 5 a copper wire No. 4 B. & S. gage, that is, a low power transmission line is represented, and in 6 a stranded aluminum conductor of the same conductivity as copper wire No. 00 B. & S. gage.

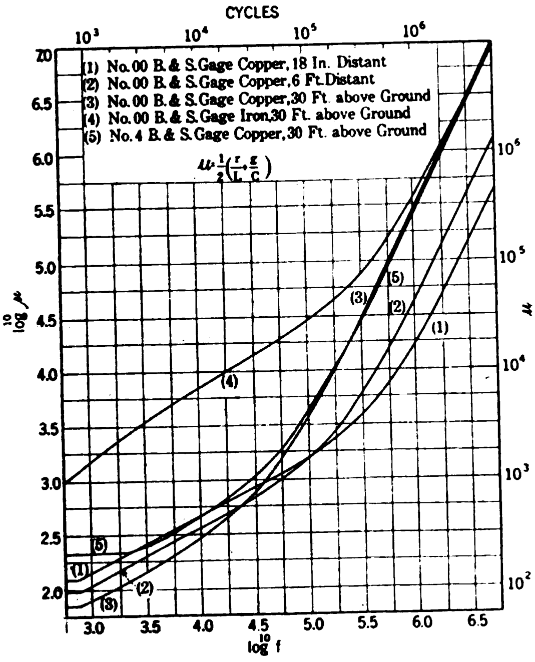

FIG. 3—ATTENUATION CONSTANT $U = 1/2\ (r/L—g/C)$ (TABLE VI)

The equations of the constants for these six circuits are given in Table V. This table also gives the limiting frequencies, between which the various formulas apply with sufficient accuracy for practical purposes, and the lower limits, where the effects become appreciable, in the various conductors.

In Fig. 3 the attenuation constants are plotted, in Fig. 4 the power factors and in Fig. 5 the duration, in cycles.

As such a transient oscillation dies out exponentially, theoretically it has no definite duration, but lasts forever, though practically it may have ceased in a few micro-seconds. Thus as duration is defined the time, or the number of cycles, which the oscillation would last if maintaining its initial intensity. In reality, in this time the duration has decreased to $\frac{1}{\epsilon}$, or 37 per cent of its initial value. Physically, at 37 per cent of its initial value, or $0.37^2 = 0.135$ of its initial energy, it has become practically harmless, so that this measure of duration probably is the most representative.

From Tables V and VI it is seen that there is no marked difference between the stranded aluminum conductor (6), and the solid copper wire of the same conductivity (3), and the values of (6) are not plotted in the figures, but may be represented by (3).

The attenuation constant u, in Fig. 3, is plotted in logarithmic scale, with $\sqrt{f}$ as abscissas. In such scale, a difference of one unit means ten times larger or smaller, and a straight line means proportionality to some power of the frequency. This figure well shows the three ranges; the initial horizontal range at low frequency, where the attenuation is constant; the approximately straight moderate slope of medium frequency, where the attenuation constant is proportional to the square root of the frequency, the unequal current distribution in the conductor predominating, and the steep slope at high frequencies, where the radiation resistance predominates, which is proportional to the square of the frequency.

It is interesting to note that at high frequencies the distance of the return conductor is the dominating factor, while the effect of conductor size and material vanishes; in copper wire No. 00 the rate of decay is practically the same as in copper wire No. 4, though the latter has more than three times the resistance, or in the iron wire, which has nearly six times the resistance and 200 times the permeability. The permeability of the iron wire has been assumed as $\mu = 200$, representing load conditions, where by the passage of the low frequency

TABLE V.
LINE_CONSTANTS.

f = frequency, in cycles per second.
$S = 3 \times 10^{10}$ cm. sec. = propagation velocity in empty space.
$K = 1$ = specific capacity.
l_0 = length of conductor, in kilometers $= 10^5$ cm.

			per kilometer of conductor:					
			(1)	(2)	(3)	(4)	(5)	(6)
	Size of round conductor, B. & S. gage:		00	00	00	00	4	(00)
	Radius of conductor, cm.:	$l_r =$	0.463	0.463	0.463	0.45	0.258	0.65
	Distance of return conductor, cm.:	$l' =$	45.5	182	1820	1820	1820	1820
	Material of conductor:		copper	copper	copper	iron	copper	aluminum
	Conductivity:	$\gamma = 10^5 +$	6.2	6.2	6.2	1.1	6.2	3.8
	Permeability:	$\mu =$	1	1	1	200	1	1
Low frequency.	Ohmic resistance	$r_0 = \frac{10^5 l_0}{\pi l^2 r \ \gamma}$ ohms =	0.240	0.240	0.240	1.35	0.770	0.240
	Internal reactance	$x_0^1 = 0.1\ \pi\mu\ f\ l_0\ 10^{-3}$ ohms $= f \times 10^{-3} \times$	0.314	0.314	0.314	62.83	0.314	0.314
	Limit, cycles:	$f =$	10^3	10^3	10^2	10	2×10^3	10^3
High frequency.	Thermal resistance, Internal reactance	$r_1 = x_1 = \frac{5\ l_0}{l r}\sqrt{\frac{0.4\ \mu f}{\gamma}}$ ohms $= 10^{-3} \times \sqrt{f} \times$	8.65	8.65	8.65	290	15.5	7.86
	Lower limit, cycles:	$f =$	2×10^5	10^5	2×10^4	2×10^5	2×10^4	2×10^4
	Radiation resistance	$r_2 = \frac{0.8\ \pi^2 f^2 l'\ l_0}{S} 10^{-3}$ ohms $= f^2 \times 10^{9-} \times$	0.012	0.048	0.48	0.48	0.48	0.48
	Upper limit, cycles:	$f =$	10	3×10^7	3×10^6	3×10^6	3×10^6	3×10^6
	External reactance:	$x_0 = 0.4\ \pi f\ l_0 \log \frac{l'}{l r} 10^{-3}$ ohms $= f \times 10^{-3} \times$	5.76	7.5	10.4	10.4	11.1	9.95
	Total resistance:	$r = r_1 \text{ (or } r_0) + r_2$						
	Total reactance:	$x = x_1 \text{ (or } x'_0) + x_0$						
	Inductance:	$L = \frac{x}{2\ \pi f}$ henrys.						
	Magnetic attenuation:	$\frac{r}{2\ L}$						
	Dielectric radiation resistance:	$r_c = \frac{2\ S\ l'}{K\ l_0} 10^{-14}$ ohms =	0.0273	0.1092	1.092	1.092	1.092	1.092
	Capacity reactance:	$x_c = \frac{S^2}{\pi f K l_0} \log \frac{l'}{l r} 10^{-14}$ ohms $= \frac{10^6}{f} \times$	13.2	17.2	23.7	23.7	25.4	22.8
	Dielectric attenuation:	$\frac{g}{2\ C} = \pi f \frac{r_c}{x_c} = \frac{2\ \pi^2 f^2 l'}{S \log \frac{l'}{l r}} = f^2 \times 10^{-6} \times$	0.0065	0.020	0.144	0.144	0.135	0.151
	Attenuation Constant:	$u = \frac{1}{2}\left(\frac{r}{L} + \frac{g}{C}\right)$						

TABLE VI.
ATTENUATION CONSTANTS.

		$f =$	10c	60	500	1,000	2,000	5,000c	10 kc	20	50	100	200	500	1,000	2,000	5,000 kc
1	No. 00 B. & S G. l_r = 0.463 cm. l' = 45.5 cm. copper	$r =$	0.24	0.24	0.24	0.273	0.386	0.612	0.866	1.230	1.96	2.85	4.34	9.12	20.65	60.25	319.3
		$\cos \omega =$	96.9	54.9	7.86	4.53	3.26	2.07	1.48	1.055	0.674	0.494	0.376	*0.316*	0.358	0.524	1.105%
		$u =$	124	124	124	142	204	327	466	666	1,081	1,615	2,620	6,595	17,740	58,800	336,500
		$N =$	0.08	0.43	4.04	7.04	9.80	15.3	21.5	30.2	46.2	64.5	*76.4*	76.0	56.4	34.0	14.9c
2	l' = 182 cm copper	$r =$	0.24	0.24	0.24	0.273	0.386	0.613	0.870	1.249	2.05	3.21	5.78	18.1	56.6	204.2	1,219
		$\cos \omega =$	95.1	45.4	6.16	3.51	2.52	1.61	1.15	0.822	0.544	0.427	*0.384*	0.483	0.753	1.36	3.25 %
		$u =$	96	96	96	110	157	252	362	524	905	1,540	3,210	12,570	43,700	165,600	1,010,000
		$N =$	0.10	0.62	5.20	9.09	12.74	19.85	27.6	38.2	55.0	*64.9*	62.2	39.8	22.9	12.1	5.0 c
3	l' = 1820 cm. copper	$r =$	0.24	0.24	0.24	0.273	0.386	0.624	0.913	1.417	3.13	7.53	23.06	126.1	488.6	1,932	12,020
		$\cos \omega =$	91.3	34.9	4.48	2.56	1.83	1.19	0.870	0.677	*0.600*	0.706	1.105	2.42	4.70	9.24	32.5 %
		$u =$	70	70	70	80	115	190	287	482	1,302	3,710	12,690	74,200	291,500	1,159,000	7,230,000
		$N =$	0:14	0.86	7.15	12.5	17.4	26.3	34.8	*41.4*	38.4	26.9	15.8	6.75	3.43	1.72	0.69 c
4	iron	$r =$	1.35	2.25	6.48	9.16	12.95	20.51	29.05	41.29	66.0	96.4	148.7	325	770	2,331	12,650
		$\cos \omega =$	(80)	61.7	48.5	42.4	35.8	27.1	21.5	16.0	11.3	8.5	6.7	*6.0*	7.2	11.0	23.3
		$u =$	(25)	148	873	1,470	2,410	4,444	6,914	10,210	18,060	28,200	48,200	130,400	371,000	1,266,000	7,370,000
		$N =$	(0.40)	0.40	0.57	0.68	0.83	1.13	1.45	1.96	2.77	3.55	*4.17*	3.83	2.70	1.58	0.68 c
5	No.4 B.&S.G. l_r = 0.258 cm. l' = 1820 cm. copper	$r =$	0.77	0.77	0.77	0.77	0.772	1.112	1.598	2.382	4.66	9.70	26.1	131	495	1,940	12,030
		$\cos \omega =$	98.9	74.5	13.4	6.75	3.38	1.96	1.42	1.06	*0.84*	0.87	1.17	2.34	4.44	8.7	21.1 %
		$u =$	212	212	212	212	213	311	458	721	1,647	4,080	12,750	70,550	274,500	1,087,000	6,775,000
		$N =$	0.047	0.28	2.36	4.72	9.38	16.05	21.8	27.8	*30.4*	24.5	15.7	7.1	3.65	1.84	0.75
6	7 strand Al. equivalent to No.00 copper l_r = 0.65 cm. l' = 1820 cm.	$r =$	0.24	0.24	0.24	0.248	0.351	0.568	0.834	1.302	2.950	7.28	22.71	125.6	487.9	1,931	12,018
		$\cos \omega =$	91.9	36.0	4.64	2.42	1.72	1.12	0.83	0.65	*0.59*	0.73	1.14	2.5	4.9	9.8	23.7
		$u =$	73	73	73	76	109	181	275	467	1,298	37.80	13,130	77,000	303,000	1,207,000	7,580,000
		$N =$	0.14	0.82	6.85	13.2	18.3	27.6	36.4	*42.8*	38.5	26.5	15.2	6.5	3.3	1.66	6.65

ower current the iron is magnetically near saturation, and its permeability thus lowered. However, the decay of the oscillation between conductor and ground is six to seven times more rapid than that between conductors 6 ft. apart, and that between conductors 18 inches apart about three times less.

This shows, that to produce quicker damping of high-frequency waves, such as are instrumental in steep wave fronts, the most effective way is to separate the conductors as far as possible, perhaps even lead them to the station by separate single conductor lines; but the use of high-resistance conductors, or of magnetic material, as iron, offers little or practically no advantage in damping very high frequencies or flattening steep wave fronts.

At medium and low frequencies however, the relation reverses, and the decay of the wave is the smaller the greater the distance of the return conductor. The reason is, that in this range the effective resistance is still independent of the conductor distance, while the inductance increases with increasing distance. At medium and low frequencies, the iron conductor offers an enormously increased attenuation—from 10 to 20 times that of non-magnetic conductors.

The power factor of the conductor is plotted in Fig. 4. As seen, it decreases from unity, at very low frequencies, to a minimum, at medium high frequencies, and then increases again to very high values at very high frequencies. The minimum value is a fraction of one per cent except with the iron conductor, where the minimum is very much higher. The power factor is of importance as it indicates the percentage of the oscillating energy, which is dissipated per wave of oscillation. This is represented still better by Fig. 5 the duration of the oscillation in cycles, that is, the number of cycles which an oscillation lasts before dissipating the stored energy which causes it.

At medium high frequencies, the oscillation is the more persistent the lower the ohmic resistance of the conductor and the further away the return conductor, while at very high frequencies the reverse is the case, and the oscillation is the more persistent, the shorter the distance of the return conductor, while the size and material of the conductor ceases to have any effect.

The maximum number of cycles is reached at medium high frequencies, in the range between 20,000 and 100,000 cycles—

depending on conductor size and distance of return conductor. It thus is in this range of frequencies, where an oscillation caused by some disturbance lasts the greatest number of cycles, that the possibility, by some energy supply by means of an arc, etc., to form a stationary oscillation or even a cumulative oscillation, thus to become continuous or "undamped", is greatest.

It would thus appear, that this range of frequencies, of 20,000 to 100,000, represents what may be called the "danger frequencies" of transmission systems. It is interesting to note, that experimental investigations have shown that the natural frequency of oscillation of the high-voltage windings of large power transformers usually is within this range of danger frequencies. The possibility of the formation of destructive cumulative oscillations or stationary waves in the high-voltage windings of large power transformers is therefore greater than probably with any other class of circuits, so that such high-

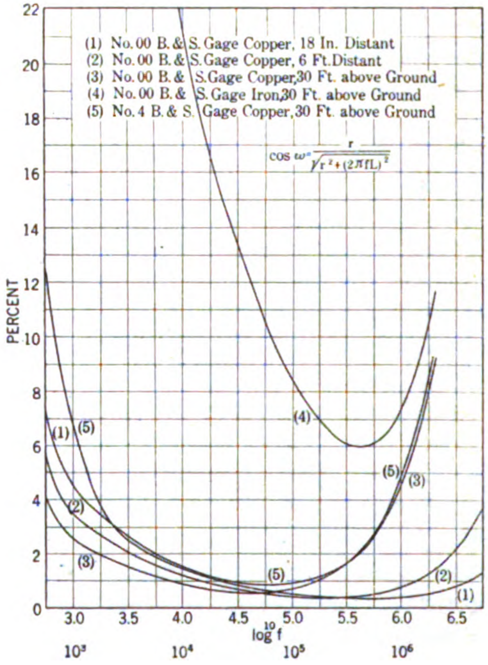

Fig. 4—Power Factor of Series Constant Cos $\omega = \frac{r}{\sqrt{r^2 + (2\pi f L)^2}}$

(Table VI)

potential transformer windings require specially high disruptive strength and protection. This accounts for the not infrequent disastrous experience with such transformers, before this matter was realized.

Fig. 5 also shows, that the duration of an oscillation in iron wire, in cycles, is very low at all frequencies. Thus the formation of a stationary oscillation in an iron conductor is practically excluded, but such conductors would act as a dead resistance, damping any oscillation by rapid energy dissipation.

The duration of high frequency oscillations, in cycles, increases with increasing frequency, to a maximum at medium frequencies. This obviously does not mean that the time during which the oscillation lasts increases; the time, in micro-seconds, naturally decreases with increasing frequency, due to the increasing attenuation constant. Thus in conductor (2) for instance, the oscillation lasts 65 cycles at a frequency of 100,000 cycles, but only 9 cycles at 1000 cycle frequency. However, the 65 cycles are traversed in 650 micro-seconds, while the 9 cycles last 9000 micro-seconds, or 14 times as long. It is not the total time of oscillation, but the cumulative effect due to the numerous and only slowly decreasing successive waves, which increases as represented in Fig. 5.

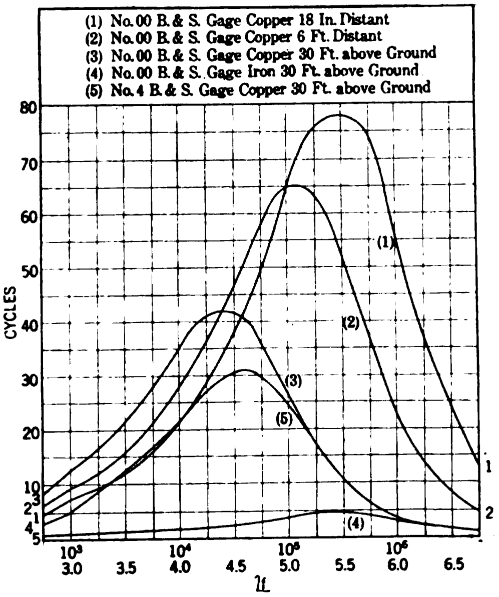

FIG. 5—DURATION OF OSCILLATION IN CYCLES (TABLE VI)

An oscillation between copper wires No. 4 B. & S. gage 6 ft. apart, would give a duration curve, which at moderate, frequencies follows (5) of Fig. 5, but at high frequencies follows (2). Thus the average duration and average rate of decay would be about the same as (3), an oscillation between copper wire No. 00 and ground. However, the oscillation would be more persistent in such a conductor at high, and less persistent at low frequencies. A complex wave, containing all the harmonics from low to very high ones, such as a steep wave front impulse or an approximately rectangular wave, as may be produced by a spark discharge, etc, would have about the same average rate of decay in a copper wire No. 4 with return at 6 ft., as in a copper wire No. 00 with ground return. The wave front would flatten, and the wave round off, approaching more and more a sine shape, due to the more rapid disappearance of the higher frequencies, while at the same time decreasing in amplitude. The wave thus would pass through many intermediate shapes. But these intermediate shapes would be materially different with wire No. 4 and return at 6 ft., as with No. 00 and ground return; in the latter, the flattening of the steep wave front, and rounding of the wave, would be much more rapid at the beginning, due to the shorter duration of the transient, and while such wave would last about the same time, that is, pass over the lines to about the same distance, it would carry steep wave fronts to much shorter distances, that is, its danger zone would be materially less than that of the wave in copper wire No.4 with return at 6 ft.

It therefore, is of great interest to further investigate the effect of the changing attenuation constant on complex waves, and more particularly those with steep wave fronts, as the rectangular waves of starting or disconnecting lines, etc.

IV.—Attenuation of Rectangular Waves

The destructiveness of high frequencies or steep wave fronts in industrial circuits is rarely due to over-voltage between the circuit conductors or between conductor and ground, but is due to the piling up of the voltage locally, in inductive parts of the circuit, such as end turns of transformers or generators, current transformers, potential regulators, etc., or inside of inductive windings as the high potential coils of power transformers, by the formation of nodes and wave crests.

Such effect may be produced by high frequency oscillations sustained over a number of cycles, as discussed in III, as oscillations lasting only a very few cycles or a fraction of a cycle, or due to non-oscillating transients, as single impulses, etc. As the high rate of change of voltage with the time, and the correspondingly high voltage gradients along the conductor are the source of danger, to calculate and compare oscillatory and non-oscillatory effects in this respect, it has become customary in the last years to speak of an "equivalent frequency" of impulses, wave fronts or other non-oscillatory transients.

As "effective" or "equivalent" frequency of an impulse, wave, front etc., is understood the frequency of an oscillation, which has the same maximum amplitude, e or i, and the same maximum gradient $\frac{de}{dt}$ or $\frac{di}{dt}$. Thus assuming an impulse which reaches a maximum voltage $e = 60{,}000$, and has a maximum rate of increase of voltage of $\frac{de}{dt} = 10^{10}$, that is, a maximum voltage rise at the rate of 10^{10} volts per second, or 10,000 volts per micro-second. As the average voltage rise of a sine wave is $\frac{2}{\pi}$ times the maximum, the average rise of an oscillation of the same maximum gradient as the impulse would be

$$\frac{2}{\pi}\,\frac{de}{dt} = \frac{20{,}000}{\pi}$$

volts per microsecond. The total voltage rise of $e = 60{,}000$ thus would occur in

$$\frac{e}{\frac{2}{\pi}\,\frac{de}{dt}} = \frac{60{,}000\pi}{20{,}000} = 9.4 \text{ micro-seconds.}$$

A complete cycle of this oscillation thus would last $4 \times 9.4 = 37.6$ micro-seconds, and the equivalent frequency of the impulse would be

$$f = \frac{10^6}{37.6} = 26{,}600 \text{ cycles or } 26.6 \text{ kilo cycles.}$$

The equivalent frequency of a perfectly rectangular wave front if such could exist, obviously would be infinity.

A. QUARTER WAVE CHARGING OR DISCHARGING OSCILLATION OF LINE

Considering first the theoretically rectangular wave of connecting a transmission line to a circuit, or disconnecting it from the circuit.

Suppose a transmission line, open at the distant end, is connected to a voltage *E*. At this moment, the voltage of the line is zero. It should be, in permanent conditions, *E*. Thus the circuit voltage consists of a permanent voltage *E* (which is the instantaneous value of the alternating supply voltage at this moment $E_0 \sin \varphi$) and the transient voltage $-E$. We thus have a transient voltage, which uniformly $= -E$ all along the line, except at the switching point $l = 0$, where the transient voltage is zero.

Or, suppose a transmission line, open at the far end, is connected to a source of voltage, and at the moment where this voltage is *E*, the line short circuits at some point, by a spark discharge, flash-over, etc. Thus at this moment, the voltage $= 0$ at the point of short circuit, and is $= E$ everywhere between this point and the end of the line. Thus we get a line discharge leading to the same transient, a theoretically rectangular wave. In the part of the line between gnerator and short circuit, we have a different transient, a circuit of voltage $e = 0$ at one end, $e = E$ throughout the entire length at time $t = 0$, and $e = E$ continuously at the other end, where the generator maintains the voltage. However, this again leads to the same transient, of a theoretically rectangular wave.

Assuming thus, as an instance, a transmission line of 100-km. length, of copper wire No. 00 B. & S. gage, 30 ft. above ground, open circuited at the other end $l = 100$ km., and connected to a source of voltage *E* at the beginning, $l = 0$.

Then the beginning of the line, $l = 0$, is grounded, at the time $t = 0$, thus giving a quarter wave oscillation, with the terminal conditions:

Voltage along the line constant $= E$, at time $t = 0$, except at the beginning of the line, $l = 0$, where the voltage is 0.

Current along the line $= 0$ at $t = 0$, except at $l = 0$, where the current is indefinite.

The equation of the quarter wave oscillation of the line conductor against ground, as usually given[1], then is:

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[1] See for instance: "Theory and Calculation of Transient Electric Phenomena," Section IV, Chapter VII, equation (57).

$$e = \frac{4\,E}{\pi}\,\epsilon^{-ut} \sum_{0}^{\infty}{}_{n} \frac{\sin\,(2\,n+1)\,\tau\,\cos\,(2\,n+1)\,\theta}{n+1} \qquad (1)$$

where:
θ is the time angle of the fundamental wave of oscillation, of frequency:

$$f_0 = \frac{S}{4\,l_0} = \frac{3 \times 10^{10}}{4 \times 100 \times 10^{5}} = 750 \text{ cycles.} \qquad (2)$$

τ is the distance angle, for $l_0 = 100$ km. $= 90° = \pi/2$, that is:

$$\left.\begin{aligned} \theta &= 2\,\pi\,f_0\,t \\ \tau &= \frac{\pi\,l}{2\,l_0} \end{aligned}\right\} \qquad (3)$$

Equation (**1**) however assumes that u, and thus r, L, C and g are constant for all frequencies. As this is not the case, but u is a function of the frequency, and thus of n: ϵ^{-ut} cannot be taken out of the summation sign. Equation (**1**) thus must be written:

$$e = \frac{4\,E}{\pi} \sum_{0}^{\infty}{}_{n}\, \epsilon^{u_n t} \frac{\sin\,(2\,n+1)\,\tau\,\cos\,(2\,n+1)\,\theta}{2\,n+1} \qquad (4)$$

where u_n is the value of u for the frequency: $f = (2\,n+1)\,f_0$.

From (**4**) follows, as the voltage gradient along the line:

$$\frac{d\,e}{d\,\tau} = \frac{4\,E}{\pi} \sum_{0}^{\infty}{}_{n}\; \epsilon^{-u_n t} \cos\,(2\,n+1)\,\tau\,\cos\,(2\,n+1)\,\theta \qquad (5)$$

$$= \frac{2\,E}{\pi} \left\{ \sum_{0}^{\infty}{}_{n}\; \epsilon^{-u_n t} \cos\,(2\,n+1)\,(\tau+\theta) + \sum_{0}^{\infty}{}_{n}\; \epsilon^{-u_n t} \cos\,(2\,n-1)\,(\tau-\theta) \right\} \qquad (6)$$

The maximum voltage gradient occurs at the wave front, that is, for $\theta = \tau$. Substituting this, and substituting further, from (**3**):

$$d\,\tau = \frac{\pi}{2\,l_0}\,d\,l \qquad (7)$$

gives, as the maximum voltage gradient:

$$G = \frac{d\,e}{d\,l} = \frac{E}{l_0} \left\{ \sum_0^\infty {}^n\, \epsilon^{-u_n t} \cos\,(2\,n + 1)\,2\,\tau + \sum_0^\infty {}^n\, \epsilon^{-\mu_n t} \right\} \tag{8}$$

It is however:

$$\sum_0^\infty {}^n \cos\,(2\,n + 1)\,2\,\tau = 0 \tag{9}$$

for all values of τ except $\tau = 0$ and $\tau = \pi$, that is, the beginning of the line, $l = 0$.

Thus, approximately, as u_n varies gradually:

$$\sum_0^\infty {}^n\, \epsilon^{-u_n t} \cos\,(2\,\pi + 1)\,2\,\tau = 0 \tag{10}$$

except for values of $\tau = 0$ or very near thereto.

Substituting (**10**) into (**8**) gives:

$$G = \frac{E}{l_0} \sum_0^\infty {}^n\, \epsilon^{-\mu_n t} \tag{11}$$

as the approximate expression of the maximum voltage gradient, that is, the steepness of the wave front, at time t, that is, at distance from the origin of the wave:

$$l = S\,t = 3 \times 10^{10}\,t \tag{12}$$

If θ differs materially from τ, the term with $(\tau - \theta)$ in equation (**6**) also vanishes, and $\frac{d\,e}{d\,\tau} = 0$, that is, there is no voltage gradient except at and near the wave front.

From (**11**) are now calculated numerical values of the steepness of the wavefront G, for various times t after its origin, and thus by (**12**), various distances l from the origin. These numerical values are given in Table VII, for $E = 60{,}000$ volts.

At a fundamental frequency of $f_0 = 750$ cycles, successive harmonics differ from each other by 1500 cycles, and for every value of t, values of $\epsilon^{-u_n t}$ thus have to be calculated for the frequencies:

$n =$	0	1	2	3	4	5	6	etc.
$f =$	750	2250	3750	5250	6750	8250	9750	cycles etc.,

until the further terms add no further appreciable amount to $\Sigma\, \epsilon^{-u_n t}$. In calculating, it is found that for instance for $t = 5$ microseconds, or $l = 1.5$ km., this occurs at $f = 5 \times 10^6$ cycle, thus beyond the $\frac{5 \times 10^6}{750} = 6670$th harmonic. Thus 6670 terms of the series would have to be calculated to get this one point of the wave gradient: more terms for shorter, less terms for longer distances l of wave travel. This obviously is impossible, and some simpler approximation, of sufficient accuracy, thus is required.

TABLE VII

ATTENUATION OF WAVE FRONT OF QUARTERWAVE OSCILLATION, OF 100 KM. LINE, 60,000 VOLTS.

Time t, micro-seconds.	Distance l km:	miles:	f, where $\Sigma\, \epsilon^{-ut}$ vanishes	Voltage $\frac{1}{E}\frac{de}{dt}$	Gradient G, volts per meter.	Wave Front: Equivalent kilo-cycles.	Length, meters.
from origin of wave.							
(3) Copper wire No. 00 B. & S. gage 30 ft. = 910 cm. above ground.							
0	0	0	—	∞	60,000	∞	0
.03	.01	.0062	....	5,800	5,500	8,800	6
.575	.1725	.107	10×10^6	1,370	1,290	2,060	73
1.15	.345	.215	8×10^6	1,025	967	1,540	98
2.3	.69	.43	6×10^6	670	630	1,000	150
11.5	3.45	2.15	4×10^6	300	280	450	330
23	6.9	4.3	2×10^6	218	205	330	460
92	27.6	17.2	10^6	104	98	156	960
230	69	43	$.7 \times 10^6$	62	58	92	1,630
2,300	690	430	$.2 \times 10^6$	13	12	19	7,900
23,000	6,900	4,300	50,000	1.3	1.2	1.9	79,000
(1) Copper wire No. 00 B. & S. gage, return conductor at 18 ins. = 45.5 cm distance.							
2.3	.69	.43	20×10^6	3,450	3,240	5,160	29
23	6.9	4.3	10×10^6	1,020	960	1,530	98
230	69	43	4×10^6	250	234	370	400
(5) Copper wire No. 4 B. & S gage, 30 ft. = 910 cm. above ground.							
23	6.9	4.3	2×10^6	227	213	340	440
230	69	43	$.7 \times 10^6$	64	60	94	1,570
(4) Iron wire No. 00 B. & S. gage, 30 ft. = 910 cm. above ground.							
23	6.9	4.3	2×10^6	143	135	215	700
230	69	43.	$.3 \times 10^6$	11	10	16	9,400

This may be done as follows:

In the range from 5×10^5 to 10^6 cycles for instance, there are $\frac{10^6 - 5 \times 10^5}{1500} = 333$ harmonics. Instead of calculating u and ϵ^{-ut} for each of these harmonics, calculate ϵ^{-ut} for the average value of these 333 harmonics, and multiply by 333.

Thus, dividing the entire frequency range (beyond the lowest harmonics, which are calculated separately), into groups, and calculating one average value for each group, the calculation of $\Sigma\ \epsilon^{-ut}$ becomes feasible.

Since ϵ^{-ut} is calculated through $\underline{/\epsilon^{-ut}} = -\,u\,t\,\underline{/\epsilon}$, as values of t, multiples of $\frac{1}{\underline{/\epsilon}}$ have been chosen, to still further simplify the calculation, in deriving a curve of gradients G.*

Table VII gives the values of the maximum voltage gradient of the wave front, in volts per meter at 60,000 volts maximum initial line voltage, the equivalent frequency of the wave front, in kilo-cycles, and the length of the wave front, in meters, for various times of wave travel, from 0.03 micro-seconds up, and corresponding distances of wave travel, from 10 meters from the origin as rectangular wave, up to thousands of kilometers, for copper wire No. 00 B. & S. gage, 30 ft. = 910 cm. above ground, with the ground as return.

TABLE VIII.

ATTENUATION OF WAVE FRONT OF QUARTERWAVE OSCILLATION, OF 100 KM. LINE, 60,000 VOLTS.

Conductor: Size No.: Material:	(3) 00 Copper	(1) 00 Copper	(5) 4 Copper	(4) 00 Iron
Distance of return conductor, cm.: ...	1820	45.5	1820	1820
After 23 microseconds, 6.9 km.:				
Gradient, volts per meter:	205	960	213	135
Length of wave front, meters:........	460	98	440	700
Equivalent kilocycles:...............	330	1530	340	215
After 230 microseconds, 69 km.:				
Gradient, volts per meter:	58	234	60	10
Length of wave front, meters:........	1630	400	1570	9400
Equivalent kilocycles:...............	92	370	94	16

For comparison are given some data of the same conductor, with the return conductor at 18 inches = 45.5 cm., and also for a copper wire No. 4, and an iron wire No. 00, with the ground as return.

These data are plotted in Fig. 6, showing the wave front, as it gradually flattens out in its travel over the line, from the very steep wave at 170 meters from the origin, to the wave with a front of 1630 meters, 69 km. away.

A comparison of the data of the four circuit conditions is given in Table VIII, and plotted in Fig. 7.

It is interesting to note, that there is practically no difference in the flattening of the wave front on a low resistance conductor, No. 00, and a high resistance conductor, No. 4. There is, however, an enormous difference due to the effect of the close-

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*Here and in the following, the symbol $\underline{/\ \ }$ has been chosen for the common logarithm.

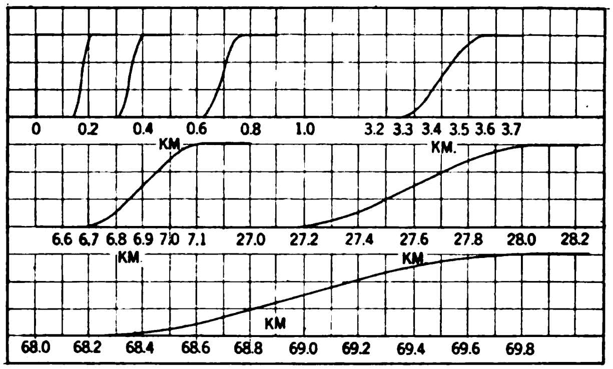


FIG. 6—FLATTENING OF STEEP WAVE FRONT IN TRANSMISSION LINE No. 00 B. &. S. GAGE COPPER 30 FT. ABOVE GROUND

ness of the return conductor; with the return conductor at 18 inches distance, the wave front is still materially steeper at 6.9 km. distance, than it is in the conductor with ground return at

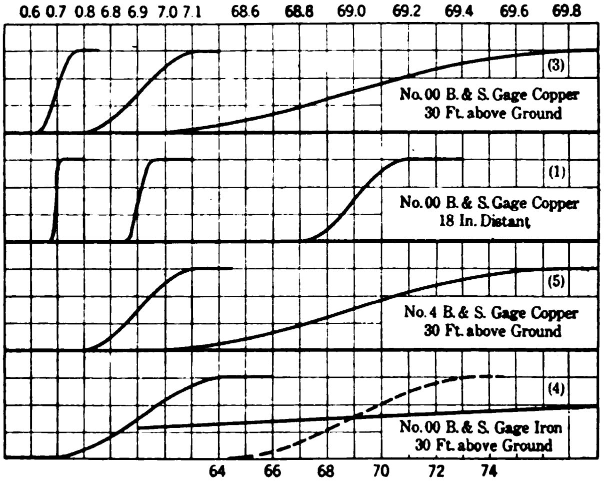
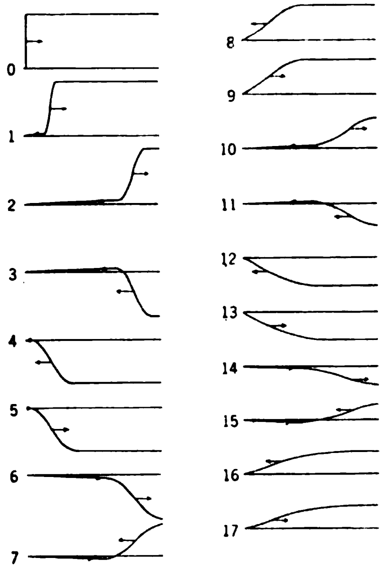


FIG. 7

0.69 km. distance. That is, the flattening of the wave front in the conductor with ground return, is more than ten times as rapid, than in the same conductor with the return conductor closely adjacent. Or in other words, the danger zone of steep wave front, extends in a conductor with the return conductor closely adjacent, to more than ten times the distance than in the conductor with ground return.

This means, where it is desired to transmit a high frequency impulse or steep wave front to the greatest possible distance, it is essential to arrange conductor and return conductor as closely adjacent as possible. But where it is essential to limit the harmful effect of very high frequency or steep wave front as much as possible to the immediate neighborhood of its origin, the return conductor should be separated as far as possible.

The data on iron wire are very disappointing; there is an enormous increase in the flattening of the wave front at great distances, by the use of iron as conductor material, so much so that the wave front of the iron conductor at 69 km. distance had to be shown (dotted) at one-tenth the scale of the other conductors, in Fig. 7. But at moderate distances, 6.9 km. from the origin, the flattening of the wave front in the iron conductor is only little greater than in a copper conductor of the same size: 215 kilo-cycles against 330 kilo-cycles. At short distances, the difference almost entirely ceases, and within one km. from the origin, the wave front in an iron conductor is nearly as steep as in a copper conductor of the same size. Thus a short length of iron wire between station and line would exert practically no protection against very high frequency oscillations or steep wave fronts, such as may be produced by lightning strokes in the neighborhood of the station.



QUARTERWAVE CHARGING OSCILLATION OF TRANSMISSION LINE

Fig. 8

This was to be expected from the shape of the curve of the attenuation constant, shown in Fig. 3.

From the data in Table VII then are constructed and shown in Fig. 8, the successive curves of voltage distribution in the line, as it is discharging (or charging), by the originally rectangular wave running over the line, reflecting at the end of the line and running back, then reflecting again at the beginning of the line and once more traversing it, etc., until gradually the transient energy is dissipated and the line voltage reaches its average, zero in discharge, or the supply voltage in charge. The direction of the wave travel in the successive positions is shown by the arrows in the center of the wave front; the existence and direction of current flow in the line by the arrows in the (nearly) horizontal part of the diagram. As seen, after four to five reflections, the voltage distribution in the line is practically sinusoidal.

However, in these diagrams Figs. 6 to 8, the wave front has been constructed from the maximum voltage gradient derived by the calculation, assuming as approximation the shape of the wave front as a sinusoid. This usually is a sufficient approximation, since the important feature is the maximum gradient, that is, the steepest part of the wave front, which was given by the calculation; but it is not strictly correct, and the wave front differs from sine shape. It thus is of interest to investigate the exact shape of the wave front, in its successive stages of flattening.

RECTANGULAR TRAVELING WAVE

For this purpose we may investigate, as a further example, the gradual destruction of wave shape and decay of a 60,000-cycle rectangular traveling wave, during its passage over a transmission line, changing from the original rectangular wave shape produced at its origin by lightning stroke, spark discharge, etc., into practically a sine wave.

For this purpose, for the elementary symmetrical traveling wave, the equation is:

$$e = \frac{4E}{\pi} \sum_{0}^{\infty}{}_{n} \epsilon^{-\kappa_n t} \sin (2n+1) \varphi \qquad (13)$$

where $\varphi = \theta - \tau$ is the running time coordinate, in angular expression.

Values of e are calculated, for various times t, from one micro-second to 360 micro-seconds, for all the angles φ, where e has not yet become constant and equal to E.

In Table IX are given numerical values, plotted in Fig. 9, of

$$e \frac{\pi}{4E} = \sum_{0}^{\infty}{}_{n} \epsilon^{-u_n t} \sin (2n + 1) \varphi,$$

rom 0 to 90 deg., and from one to 360 micro-seconds, and derived therefrom, the values of the length of wave front, in degrees and in meters, and the equivalent frequency, in kilo-cycles. Two values are given, the maximum kilo-cycles, derived from the steepest part of the wave front, and the average kilo-cycles, derived from the total wave front. The difference indicates the deviation of the shape of the wave front from a sinusoid.

TABLE IX.

ATTENUATION OF 60,000 CYCLE RECTANGULAR WAVE, IN LINE OF NO. 00 B. & S. GAGE COPPER, 30 FT. ABOVE GROUND.

Time: t = Wave travel; l =	0 0	1 .3	2 .6	5 1.5	10 3	20 6	40 12	100 30	360 108	m.s. km.
φ = 0 degrees	0.785	0	0	0	0	0	0	0	0	0
1 "	....	0.250	0.170	0.106	0.074	0.052	0.347	0.022	0.010	
5 "	....	0.785	0.645	0.475						
10 "	....	....	0.785	....	0.606	0.468	0.582	0.217	0.100	
20 "	....	....	....	0.783	0.770	0.707	0.709	0.405	0.193	
30 "	....	....	....	....	0.780	0.762	0.740	0.547	0.282	
40 "	....	....	....	....	....	0.775	0.758	0.639	0.360	
50 "	....	....	....	....	....	....	0.765	0.691	0.426	
60 "	....	....	....	....	....	....	....	0.722	0.476	
70 "	....	....	....	....	....	....	....	0.730	0.513	
80 "	....	....	....	....	....	....	....	....	0.535	
90 "	0.785	0.785	0.785	0.783	0.780	0.775	0.765	0.730	0.540	
Wave Front degrees:	σ	10	16	26	44	70	90	140	180	
Wave Front meters:	σ	140	220	340	620	980	1250	1940	2500	
Wave Front kilo-cycles: max:	∞	1110	750	470	325	230	165	103	63	
Wave Front kilo-cycles: avg:	∞	1080	670	420	268	155	120	77	60	
Highest apprec. harmonic	∞	61	45	33	15	9	7	3	1	
Decrease of wave max:	0	....	....	....	0.6	1.3	2.6	7.0	31.2	%
Maximum gradient volts per meter:	∞	690	470	295	205	140	100	65	40	

As seen, due to the high fundamental frequency, 60,000 cycles, the number of significant harmonics is very greatly reduced, until frequencies are reached where the attenuation is so enormous, that the destruction of the wave by its energy dissipation occurs in a few meters.

Thus after one micro-second, or 300 meters wave travel, the calculation needs to extend only to the 61st harmonic; after two micro-seconds, to the 45th harmonic, etc., while after 100 micro-seconds, or 30 km. travel, only the third harmonic is still appreciable, and after 360 micro-seconds, or 108 km. travel, even this has disappeared, and the wave is essentially a sine wave.

In 30 km. travel, the wave maximum has decreased 7 per cent; in 108 km. it has decreased 31.2 per cent.

It is important to note however, that waves of relatively high frequency, within the range of the danger frequencies between 20 and 100 kilo-cycles, can travel considerable distances, if no other causes of rapid attenuation are at work but those considered here, and still retain a large part of their energy. Thus the 60,000-cycle wave, after traversing 100 km. of line, still retains about 70 per cent of its amplitude, that is, about 1/2 of its energy. Thus the danger from resonance of power transformer windings with such frequencies is not local but rather extends over a large part of the system.

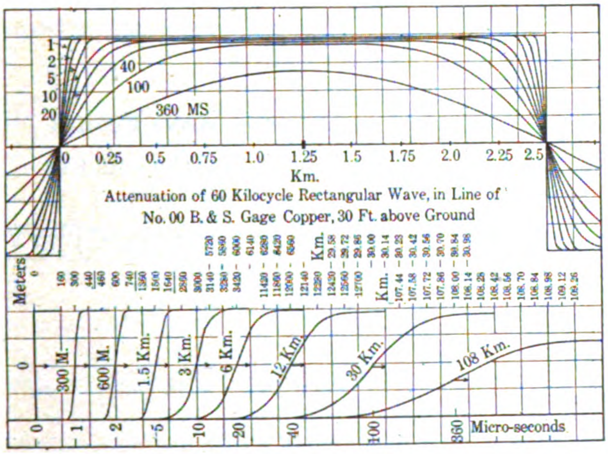


Fig. 9

The lower part of Fig. 9 shows the shape of the wave front at various distances from the origin; the upper part shows the gradual change of the wave from rectangular to flat top to sine wave.

Plotting for the 750-cycle quarter wave oscillation and the 60,000-cycle traveling wave, the logarithm of the length of the wave front, and of the equivalent frequency of the wave front, against the logarithm of the distance of wave travel, gives practically straight lines, (except for very great distances of wave travel, where the lower harmonics predominate), and from the slope of these lines it follows that: The length of wave front is approximately proportional and the equivalent frequency of the wave front approximately inversely proportional to the square root of the distance of wave travel:

$$l_f = c_1 \sqrt{l} \tag{14}$$

$$f_f = \frac{c_2}{\sqrt{l}} \tag{15}$$

This would give a wave front constant c_1 and an equivalent frequency constant c_2 of the circuit.

V.—Flattening of Steep Wave Fronts

A rectangular wave is represented by the equation

$$e = \frac{4\,E}{\pi} \sum_{0}^{\infty}{}_{n}\ \epsilon^{-ut}\ \frac{\sin\,(2\,n+1)\,\tau \cos\,(2\,n+1)\,\theta}{2\,n+1} \tag{1}$$

where

$$\theta = 2\,\pi\,f_0\,t = \text{ time angle,} \tag{2}$$

$$\tau = 2\,\pi\,\frac{l}{l_0} = \text{ distance angle,} \tag{3}$$

$f_0 =$ fundamental frequency,

$$l_0 = \frac{S}{f_0} = \text{ wave length,} \tag{4}$$

$S = 3 \times 10^{10} =$ velocity of propagation,
$E =$ maximum voltage of wave.

The voltage gradient is

$$\frac{d\,e}{d\,l} = \frac{d\,e}{d\,\tau}\,\frac{d\,\tau}{d\,l}$$

$$= \frac{4\,E}{\pi}\,\frac{d\,\tau}{d\,l} \sum_{0}^{\infty}{}_{n}\ \epsilon^{-ut} \cos\,(2\,n+1)\,\tau \cos\,(2\,n+1)\,\theta \tag{5}$$

Substituting for $\frac{d\tau}{dl}$ from (**3**), and resolving the cos-product, gives:

$$\frac{de}{dl} = \frac{4E}{l_0}\left\{\sum_0^\infty{}_n\, \epsilon^{-ut} \cos (2n+1)(\tau-\theta) + \sum_0^\infty{}_n\, \epsilon^{-ut} \cos (2n+1)(\tau+\theta)\right\} \qquad (\mathbf{6})$$

$\sum_0^\infty{}_n\, \epsilon^{-ut} \cos (2n+1)(\tau+\theta)$ approaches zero for $\tau + \theta \pm 0$. (**7**)

thus:

$$\frac{de}{dl} = \frac{4E}{l_0}\sum_0^\infty{}_n\, \epsilon^{-ut} \cos (2n+1)(\tau-\theta) \qquad (\mathbf{8})$$

The maximum voltage gradient occurs for $\theta = \tau$, and thus is:

$$G = \frac{de}{dl} = \frac{4E}{l_0}\sum_0^\infty{}_n\, \epsilon^{-ut} \qquad (\mathbf{9})$$

This can be written in the form:

$$G = \frac{2E}{f_0 l_0}\sum_0^\infty{}_n\, 2f_0\, \epsilon^{-ut} \qquad (\mathbf{10})$$

It is however, by (**4**):

$$f_0 l_0 = S \qquad (\mathbf{11})$$

thus:

$$G = \frac{2E}{S}\sum_0^\infty{}_n\, 2f_0\, \epsilon^{-ut} \qquad (\mathbf{12})$$

The values of ϵ^{-ut} are taken for all values of frequency differing from each other by $2f_0$, and, at and near the wave front, the value of $\sum_0^\infty{}_n\, 2f_0\, \epsilon^{-ut}$ thus approaches the value of

$$\int_0^\infty \epsilon^{-ut}\, df$$

Substituting this into (**10**), gives as the equation of the maximum steepness of wave front:

$$G = \frac{d\,e}{d\,l} = \frac{2\,E}{S} \int_0^\infty \epsilon^{-ut}\,d\,f \qquad (\mathbf{12})$$

As seen, in this expression (**12**), wave length and frequency have disappeared. Equation (**12**) thus applies to any wave, whether of finite length or not. That is, it represents broadly (though only approximately) the maximum gradient of any steep wave front or impulse, at the time t after its origin as rectangular wave front or impulse.

TABLE X.

ATTENUATION OF WAVE FRONT OF RECTANGULAR IMPULSE.

Copper Wire No. 00 B. & S. gage, 30 ft. above Ground, Ground Return.

f:	u:	$f\epsilon^{-ut}$; $t =$				
		10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}
1	70	1	1			
2	"	2	2			
5	"	5	5			
10	"	9	10	88		
20	"	19	20			
50	"	47	50			
10^2	"	93	99	100		
2×10^2	"	186	198	200	8,888	
5×10^2	"	468	496	500		
10^3	80	923	992	1,000		
2×10^3	115	1,760	1,970	2,000		
5×10^3	190	4,150	4,920	5,000		
10^4	287	7,500	9,720	9,999	10,000	88,888
2×10^4	482	10,200	19,000	19,900	20,000	
5×10^4	1,300	10,800	44,000	49,400	50,000	
10^5	3,710	2,450	69,000	96,400	99,500	100,000
2×10^5	12,690	1	56,100	176,000	197,000	200,000
5×10^5	74,200	0	240	190,000	466,000	498,000
10^6	291,500	......	o	54,300	748,000	970,000
2×10^6	1,160,000	......	......	18	625,000	1,780,000
5×10^6	7,230,000	......	......	o	3,660	1,860,000
10^7	28,800,000	......	......	......	1	562,000
2×10^7	115,000,000	......	......	......	o	200
	$\Sigma =$	38,660	206,800	605,000	2,230,000	6,060,000
	$+ 3 \times .4343 =$	29,700	158,700	464,000	1,710,000	4,650,000
	$G = \frac{2E}{S} \times ; =$	.119	.635	1.86	6.84	18.6
	[l =	300	30	3	.3	.03 km.]

As u is not a simple function of f, the integration of $\int_0^\infty \epsilon^{-ut}$

df in its general form meets with difficulties, and the integral may be evaluated as follows:

Equation (12) can be written in the form

$$G = \frac{2E}{S} \int_{-\infty}^{+\infty} f \epsilon^{-ut} \, d \log f \tag{13}$$

Plotting then $f \epsilon^{-ut}$ as ordinates, with $\log f$ as abscissas, gives a curve, and the area of this curve gives the integral.

Instead of using $\log f$ as abscissas, it is more convenient to

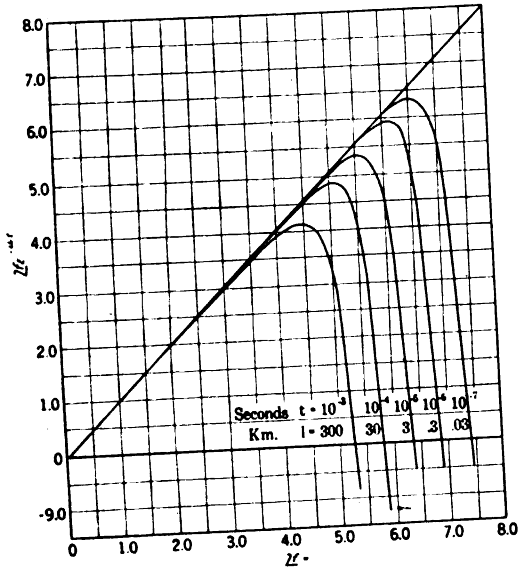


FIG. 10—ATTENUATION OF RECTANGULAR WAVE FRONT OF IMPULSE

use the common logarithm, $\underline{/f}$, and divide the measured area by $\underline{/\epsilon} = 0.4343$.

Numerically, the integration is done by calculating $f \epsilon^{-ut}$ for (approximately) constant intervals of $\underline{/f}$, adding all the values, and multiplying the sum by the (average) difference between successive $\underline{/f}$.

As an instance is given, in Table X, the calculation for circuit (3) of the preceding, that is, copper wire No. 00 B. & S. gage, 30 ft. above ground, with the ground as return conductor, for the times $t = 0.1$, 1, 10, 100 and 1000 micro-seconds, corresponding to the distance of travel of the wave front of .03, .3, 3, 30 and 300 km. As frequency intervals are selected: 1, 2, 5, 10, 20, 50, 100, 200 etc., giving the logarithms: 0, 0.3, 0.6, 1, 1.3 etc.

These curves are plotted, in logarithmic scale, in Fig. 10.

As seen, all these curves rise as straight lines under 45 degrees, and then very abruptly drop to negligible values.

In Table X, the values of $f\,\epsilon^{-ut}$ are added, then divided by three, since there are three intervals for each unit of $\underline{/f}$, and multiplied by $\underline{/\epsilon}$, to reduce to natural logarithms. Multiplying by E/S then gives the gradient G.

For medium and high frequencies, the attenuation constant u is given by the equations of appendix C as:

$$u = \frac{r_1 + r_3}{2\,(L_1 + L_0)} + \frac{g}{2\,C} \tag{14}$$

Neglecting the internal inductance L_1, as small compared with the external inductance, this gives

$$\left.\begin{aligned} u &= \frac{\dfrac{\pi}{l_1}\sqrt{2.5\,\dfrac{\mu}{\gamma}}\,10^4}{\log\dfrac{l'}{l_r}}\sqrt{f^1} + \frac{4\,\pi^2\,l'}{S\log\dfrac{l'}{l_r}}\,f^2 \\ &= m_1\sqrt{f} + m_2\,f^2 \end{aligned}\right\} \tag{15}$$

where

$$m_1 = \frac{\pi\sqrt{2.5\,\dfrac{\mu}{\gamma}}}{l_1\log\dfrac{l'}{l_r}}\,10^4 \tag{16}$$

$$m_2 = \frac{4\,\pi^2\,l'}{S\log\dfrac{l'}{l_r}} \tag{17}$$

For the conductor (3) in Table X, it is:

$$\left.\begin{aligned} m_1 &= 2.6 \\ m_2 &= .29 \times 10^{-6} \end{aligned}\right\} \tag{18}$$

This expression (15) of u holds for all frequencies except very low frequencies—below 1000 cycles— and extremely high frequencies—many millions of cycles. The latter are of little importance, as they are wiped out in the immediate neighborhood of the origin of the rectangular impulse. At the low frequencies, the attenuation is so small, within the distances which come into consideration in the wave travel, and these low frequencies give such a small part of the wave front gradient, that the error made by the use of (**15**) is negligible. For instance, in the case of Table X, even at $t = 100$ microseconds, or 10 km. wave travel, the error made in the voltage gradient by altogether neglecting the attenuation of the frequencies up to 1000 cycles, would be only 0.01 per cent.

Thus the equation (**15**) of the attenuation constant can safely be used for all practical purposes.

As the first term in equation (**15**) is proportional to $\sqrt{f}$, the second term to f^2, the second term is negligible at low and medium frequencies, while the first term is negligible at high frequencies.

Both terms are equal at:

$$f = \left(\frac{m_1}{m_2}\right)^{2/3} \qquad (\mathbf{19})$$

That is, in the above instance, at

$$f = 43{,}000 \text{ cycles.}$$

Thus, for high frequencies, that is, within moderate distances from the origin of the rectangular impulse—up to some kilometers—the first term can be neglected and the attenuation constant expressed by

$$u = m_2 f^2 \qquad (\mathbf{20})$$

The integral in equation (**12**) then becomes,

$$F = \int_0^\infty \epsilon^{-m_2 t f^2} \, d f \qquad (\mathbf{21})$$

Substituting:

$$x^2 = m_2 t f^2$$

gives:

$$d f = \frac{d x}{\sqrt{m_2 t}}$$

and:

$$F = \frac{1}{\sqrt{m_2 t}} \int_0^\infty \epsilon^{-x^2} \, d x$$

It is however:

$$\int_0^\infty \epsilon^{-x^2}\, d\, x = 1/2\, \sqrt{\pi} \tag{22}$$

thus:

$$F = \frac{1}{2} \sqrt{\frac{\pi}{m_2\, t}} \tag{23}$$

and:

$$G = \frac{E\, \sqrt{\pi}}{S\, \sqrt{m_2\, t}} \tag{24}$$

or, since:

$$l = S\, t \tag{25}$$

$$G = \frac{E\, \sqrt{\pi}}{\sqrt{m_2\, S\, l}} \tag{26}$$

Substituting (**17**) into (**26**), gives; in cm. and volts per cm.:

$$G = \frac{E}{2} \sqrt{\frac{\log \frac{l'}{l_r}}{\pi\, l'\, l}} \tag{27}$$

$$= 0.282\, E \sqrt{\frac{1}{l'\, l} \log \frac{l'}{l_r}}$$

Thus; approximately, the maximum gradient, or steepness of the wave front of a rectangular impulse, in the neighborhood and at moderate distances from its origin, decreases inversely proportional with the square root of the distance or time of wave travel.

It decreases with increasing distance l' of the return conductor, nearly in inverse proportion to the square root of l'

For the six types of circuits considered in the previous instances, it is:

	G =	$/G\sqrt{l}$ =
(1) Copper wire 00 B. & S, gage, 18 in. = 45.5 cm. from return con.:	$\frac{1}{\sqrt{l}} \times 1700$	3.230
(2) Copper wire " " " 6 ft. = 182 " " " "	968	2.986
(3) Copper wire " " " 60 ft. = 1820 " " " "	360	2.556
(4) Iron wire " " " 60 " = 1820 " " " "	360	2.556
(5) Copper wire 4 " " 60 " = 1820 " " " "	373	2.572
(6) Aluminum, stranded, same conductivity and arrangement as (3):	353	2.548

where G is given in volts per meter, at $E = 60{,}000$ volts, and l in kilo-meters:

$$\left.\begin{aligned} G &= 89 \times 10^{-3}\, E \sqrt{\frac{1}{l'l} \log \frac{l'}{l_r}} \\ &= 135 \times 10^{-3}\, E \sqrt{\frac{1}{l'l}\, \underline{/\, \frac{l'}{l_r}}} \\ &= 8100 \sqrt{\frac{1}{l'l}\, \underline{/\, \frac{l'}{l_r}}} \end{aligned}\right\} \qquad (\mathbf{28})$$

From Tables X, IX, and VII are collected the values of wave gradients G, and given in Table XI, together with their logarithms, and the $\underline{/\, G_0}$, calculated from equation (**28**), for comparison of the different methods of calculation. Table XI then gives the difference Δ, and its value in per cent.

The values of G are plotted in Fig. 11. The drawn line gives the values calculated by equation (**28**); the three cornered stars the values from Table X, the crosses the values from Table IX, and the circles the values from Table VII.

As seen from Table XI and Fig. 11, the agreement of the equations (**27**) and (**28**) is satisfactory with the values of the wave front gradient taken from Tables X and IX.

The values of G from Table X differ erratically. This table was calculated by graphical integration, and it is probable that the intervals have been chosen too large, in that range where the curve drops very abruptly, as seen in Fig. 10.

The agreement with the values from Table IX is very close. In this table, representing the course of a 60,000-cycle rectangular traveling wave, the individual harmonics have been calculated, as they were relatively few, due to the high frequency of the fundamental. This agreement is important as it justifies equation (**27**). In deriving (**27**), we have substituted integration for summation, that is, have replaced the discontinuous values of the individual harmonics by a continuous curve. Any error resulting from this should be greatest where the number of discontinuous harmonics is the least. Table XI and Fig. 11 however, show that the agreement of the gradient of the 60,000 cycle traveling wave with equation (**27**), is good even at $l = 30$ km., where only two significant harmonics are left, the fundamental and the third harmonic.

Thus the method of deriving an equation for G by integration is justified.

Unsatisfactory however, is the agreement of equation (**27**) with the values of the gradient of the quarter wave oscillation, taken from Table VII. These values lay on a straight line in Fig. 11, given as dotted line, showing proportionality with the square root of the distance, but there is a constant error, and the gradients given in Table VII are about 50 per cent greater than those given by equation (**27**).

TABLE XI.

CALCULATION OF WAVE FRONT.

Copper Wire No. 00 B. & S. gage, 30 ft. above Ground.

Dist. l km.	Gradient, volts per meter at E = 60,000 V.				
	G:	$\underline{l}\,G$:	$\underline{l}\,G_0$*	Δ	= %
Impulse, f_0 = 0: (Table X)					
.03	1860	3.269	3.317	+ .048	+ 11.7
.3	684	2.835	2.817	− .018	− 4.3
3	186	2.269	2.317	+ .048	+ 11.7
30	63.5	1.803	1.817	+ .014	+ 3.3
300	11.9	1.075	1.317	(+ .242)	
Traveling Wave, f_0 = 60,000: (Table IX)					
.3	690	2.839	2.817	− .022	− 5.2
.6	470	2.672	2.667	− .005	− 1.1
1.5	295	2.470	2.468	− .002	− 0.5
3	205	2.312	2.317	+ .005	+ 1.1
6	140	2.146	2.167	+ .021	+ 5.0
12	100	2.000	2.016	+ .016	+ 3.7
30	65	1.813	1.817	+ .004	+ 0.9
108	40	1.602	1.539	(− .063)	
Quarterwave, f_0 = 750: (Table VII)					
.01	5500	3.740	3.556	− .184	
.1725	1290	3.111	2.938	− .173	
.345	967	2.985	2.787	− .198	
.69	630	2.799	2.637	− .162	
3.45	280	2.447	2.287	− .160	
6.9	205†	2.312	2.137	− .175	
27.6	98	1.991	1.836	− .155	
69	58	1.763	1.637	(− .125)	
690	12	1.079	1.137	(+ .058)	
6900	1.2	.079	.637	(+ .558)	
Same, 18 ins. = 45.5 cm. between conductors.					
.69	3240	3.510	3.311	− .199	
6.9	960	2.982	2.811	− .171	
69	234	2.369	2.311	(− .058)	

*Calculated by equation (28).

†131 to 293

The cause of the discrepancy probably is in the method used in calculating the gradients of the quarterwave oscillation given in Table VII. Due to the impossibility of calculating individually thousands of harmonics, the number of harmonics in successive intervals of frequency, has been multiplied with the average attenuation ϵ^{-ut} in this frequency range, and as the average has been used the mean value of the ϵ^{-ut} for the two extremes of the frequency range. However, ϵ^{-ut} drops exponentially and with great rapidity, so that the true average value is much lower than the average of maximum and minimum. Thus for instance in the range from 5×10^5 to 10×10^5 cycles, containing 334 harmonics, ϵ^{-ut} for $f = 5 \times 10^5$ (at $t = 23 \times 10^{-6}$ seconds), is 1.22×10^{-3} and for $f = 10 \times 10^5$, it is 181×10^{-3}, giving an average of 91.1×10^{-3}. However, for $f = 7.5 \times 10^5$, ϵ^{-ut} is 22.5×10^{-3}, thus less than a quarter of the average.

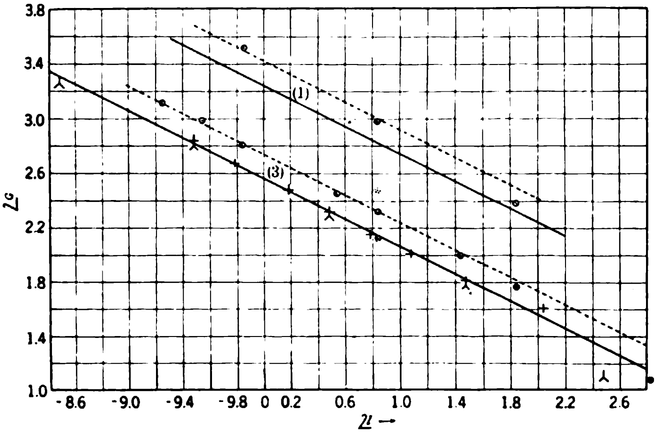


FIG. 11—WAVE FRONT GRADIENT

To check this, one value, at $t = 23 \times 10^{-6}$ or $l = 6.9$ km., has been re-calculated by using not the average, but the maximum and the minimum of ϵ^{-ut} in each interval, and the two gradients derived therefrom: $G = 293$ and 131, are marked with dotted circles in Fig. 11. As seen, the use of the minimum value of ϵ^{-ut} agrees nearer with equation (**27**), as was to be expected.

It appears probable that the equation (**27**) gives more reliable values of wave front gradient, within the range of its applicability, than the method of calculation used in Table VII. and as it is much simpler, it is preferable.

As seen from Table XI and Fig. 11, the parabolic law of wave front flattening, given by equations (**27**) and (**28**), holds good up to about 30 km. distance of wave travel, and with fair approximation even to 100 km. In the range beyond this—which is of lesser importance, as the flattening of the wave front has greatly reduced its danger at these distances—the values of the gradient G decrease with increasing rapidity, with distance and time, due to the medium high harmonics showing in the attenuation.

At great distances from the origin of the rectangular wave, when the very high harmonics have practically died out and the wave attenuation is determined by the medium-frequency harmonics, the second term of u in equation (**15**) becomes negligible, and u can be approximated by:

$$u = m_1 \sqrt{f} \qquad \textbf{(37)}$$

The integral in equation (**12**) then becomes

$$F = \int_0^\infty \epsilon^{-m_1 t \sqrt{f}} \, d f \qquad \textbf{(38)}$$

Substituting:

$$m_1 t \sqrt{f} = x$$

gives

$$d f = \frac{2 x d x}{m_1^2 t^2}$$

and

$$F = \frac{2}{m_1^2 t^2} \int_0^\infty x \epsilon^{-x} d x$$

It is however:

$$\int_0^\infty x \epsilon^{-x} d x = 1 \qquad \textbf{(39)}$$

thus

$$F = \frac{2}{m_1^2 t^2} \qquad \textbf{(40)}$$

and

$$G = \frac{4 E}{S m_1^2 t^2} \qquad \textbf{(41)}$$

or:

$$G = \frac{4\,S\,E}{m_1^2\,l^2} \tag{42}$$

Substituting (**16**) gives

$$G = \frac{1.6\,S\,\gamma\,l_1^2\left(\log\frac{l'}{l_r}\right)^2}{\pi^2\,\mu\,l^2}\,E \tag{43}$$

That is, at great distances (or considerable time) from the origin, the flattening of the wave front approaches inverse proportionality with the square of the distance (or time) of the wave travel.

However, this range is of little importance.

APPENDIX A

Unequal Current Distribution in Conductor

It is simple to determine from conductor size and material, and the frequency, whether the unequal current distribution in the conductor is sufficient to appreciably effect the ohmic resistance.[1] Also, if conductor size and frequency are so high that the current penetrates only a thin surface layer of the conductor, the calculation of its effective resistance leads to simple expressions. Only in the intermediary range, where the current distribution throughout the conductor is already very uneven, but appreciable current still penetrates to the center of the conductor, the numerical calculation becomes laborious, involving a slowly convergent series or special functions of which tables are rarely available. However, this range is relatively narrow and can be approximated between the two extremes, with sufficient accuracy for the calculation of transients, while for low-frequency power transmission, conductors of a size reaching into this range would not be used, being uneconomical in conductor material.

As the case of such high frequencies or large conductor sizes, that the current penetrates only a surface layer, has been frequently investigated,[2] the derivation of the equations is unnecessary here. The most satisfactory way of representing it is to calculate the "depth of penetration" of the current into the conductor. The actual or effective resistance of the conductor then is given by circumference of the conductor, times the depth of penetration. This method, of calculating the depth of penetration, has the advantage that it applies to all sizes and shapes of conductors, solid round conductors or hollow tubes, flat ribbon and even such complex shapes as the railway rail, provided only that the depth of penetration is materially less than the depth of the conductor material.

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[1] "Theory and Calculation of Alternating Current Phenomena, 5th edition, page 144.

[2] See for instance "Theory and Calculation of TransientPhenomena," Section III, Chapter VII.

The depth of the penetration into the conductor is

$$\left.\begin{aligned} l_p &= \frac{10^4}{\pi \sqrt{0.4\,\gamma\,\mu\,f}} \\ &= \frac{5030}{\sqrt{\gamma\,\mu\,f}} \end{aligned}\right\} \qquad (1)$$

where

γ = electrical conductivity of the conductor,
μ = magnetic permeability of the conductor,
f = frequency.

The effective resistance of the conductor then is, per unit length,

$$\left.\begin{aligned} r &= \frac{1}{\gamma\, l_p\, l_1} \\ &= \frac{\pi}{l_1} \sqrt{\frac{0.4\,\mu\,f}{\gamma}}\; 10^{-4} \\ &= \frac{\sqrt{\dfrac{\mu\,f}{\gamma}}}{5030\, l_1} \text{ ohms per cm.} \end{aligned}\right\} \qquad (2)$$

where

l_1 = circumference of conductor (actual, that is, following all indentations, etc.)

As the true ohmic resistance of the conductor is,

$$r_0 = \frac{1}{\gamma\, s} \text{ ohms per cm.} \qquad (3)$$

where

s = conductor section,

the "resistance ratio", or ratio of the effective resistance of unequal current distribution, to the true ohmic resistance, is:

$$\left.\begin{aligned}\frac{r}{r_0} &= \frac{s\,\pi}{l_1}\sqrt{0.4\,\gamma\,\mu\,f}\\ &= \frac{s}{5030\,l_1}\sqrt{\gamma\,\mu\,f}\end{aligned}\right\}\qquad(4)$$

The internal reactance of unequal current distribution equals the resistance, in the range considered:

$$x_1 = r_1 \qquad (5)$$

while at low frequency, where the current distribution is still uniform, the internal reactance is, per unit length of conductor:

$$\left.\begin{aligned}x_{10} &= \pi\,f\,\mu\,10^{-9} \text{ henry per cm.}\\ &= \pi\,f\,10^{-9} \text{ for air } (\mu = 1)\end{aligned}\right\}\qquad(6)$$

The external inductance of the conductor, that is, the inductance due to the magnetic field outside of the conductor, calculated in the usual manner, that is neglecting the finite velocity of the magnetic field, is, per unit length of conductor,

$$L_0 = 2 \log \frac{l'}{l_r}\, 10^{-9} \text{ henry per cm.} \qquad (7)$$

where

l_r = radius of conductor
l' = distance of return conductor

or, for conductors of other shape, approximately:

$$L_0 = 2 \log \frac{2\,\pi\,l'}{l_2}\, 10^{-9} \text{ henry per cm.} \qquad (8)$$

where:

l_2 = shortest circumference of conductor (that is, not including indentations etc.)

Thus, the external reactance, per unit length of conductor is:

$$x_0 = 4\,\pi\,f \log \frac{l'}{l_r}\, 10^{-9} \qquad (9)$$

$$= 4\,\pi\,f \log \frac{2\,\pi\,f'}{l_2}\, 10^{-9} \text{ ohms per cm.} \qquad (10)$$

As the unequal current distribution in the conductor, and the increase of effective resistance and decrease of internal reactance caused by it, are the result of the magnetic field of the current inside of the conductor, it follows that stranding the conductor does not eliminate this effect, unless the stranding is done in such manner that every strand has the same distance from the conductor surface, that is, interior strands interchange periodically with exterior ones and inversely, and the individual strands are insulated from each other.

Otherwise the stranding has an indirect effect only, in reducing γ and μ in equation (**1**) etc.

Thus, if in the stranded conductor the part p is filled by the conductor material of conductivity γ_0,—the rest $(1 - p)$ being the space between the strands—, then the average conductivity of the conductor is

$$\gamma = p\, \gamma_0$$

In conductors of magnetic material stranding may materially reduce the effective resistance, as the spaces between the strands would greatly reduce the resultant permeability of the conductor, and thereby greatly increase the penetration of the current into the conductor.

APPENDIX B

Radiation Resistance, Inductance and Capacity

Consider a finite section of an infinitely long conductor of radius l_r, with the return conductor at distance l', and assume that l' is small compared with a quarter wave length of the electric field of the conductor.

$$\left.\begin{aligned} \text{Let } i &= I \cos(\theta - \alpha) = \text{current in the conductor} \\ e &= E \cos(\theta - \beta) = \text{voltage of the conductor} \end{aligned}\right\} \quad (\mathbf{1})$$

At a distance l from the conductor, the magnetic field intensity is $0.2/l$ times the current, and lags behind the current by the time required for the magnetic field to travel the distance l, that is, by the angle $a\, l$, where:

$$a = \frac{2\,\pi f}{S} \quad (\mathbf{2})$$

f = frequency,

$$S = 3 \times 10^{10} = \text{velocity of radiation} \quad (\mathbf{3})$$

The magnetic field intensity thus is given by:

$$H = \frac{0.2\, I \cos(\theta - \alpha - a\, l)}{l} \tag{4}$$

The magnetic component of field, per unit length of conductor (cm.), thus is:

$$\Phi = \int_{l_r}^{l'} H\, d\, l$$

$$= 0.2\, I \int_{l_r}^{l'} \frac{\cos(\theta - \alpha - a\, l)}{l}\, d\, l$$

$$= 0.2\, I \left\{ \cos(\theta - \alpha) \int_{l_r}^{l'} \frac{\cos a\, l}{l}\, d\, l \right.$$

$$\left. + \sin(\theta - \alpha) \int_{l_r}^{l'} \frac{\sin a\, l}{l}\, d\, l \right\} \tag{5}$$

It is however, for values of l' up to about one-half of a quarter wave length of the electric field, with sufficient approximation*:

$$\int_{l_r}^{l'} \frac{\sin a\, l}{l}\, d\, l = a\, l' \tag{6}$$

$$\int_{l_r}^{l'} \frac{\cos a\, l}{l}\, d\, l = \log \frac{l'}{l_r} \tag{7}$$

Thus $\Phi = 0\ 2\, I \left\{ \log \frac{l'}{l_r} \cos(\theta - \alpha) \right.$

$$\left. + a\, l' \sin(\theta - \alpha) \right\} \tag{8}$$

Similar considerations apply to the dielectric field of the conductor, in relation to its voltage.

---

*See "Theory and Calculation of Transient Electric Phenomena," Section III, Chapter VIII: "Velocity of Propagation of Electric Field."

Thus, the two components of the electric field, the magnetic field and the dielectric field, are not in phase with current and voltage, respectively, but lag behind, due to the appearance of the sine component, resulting from the finite velocity of the electric field.

The magnetic field Φ induces α voltage in quadrature with the field Φ:

$$\begin{aligned} e' &= 2\,\pi\,f\,\frac{d\,\Phi}{d\,\theta}\,10^{-8} \\ &= 4\,\pi\,f\,I\left\{\log\frac{l'}{l_r}\sin\,(\theta-\alpha)+a\,l'\cos\,(\theta-\alpha)\right\}10^{-9} \end{aligned} \tag{9}$$

where the 10^{-8} reduces from absolute units to volts.

The reactive or sine component of this voltage e' is the e.m.f. of self induction, and gives rise to the reactance,

$$x = 4\,\pi\,f\log\frac{l'}{l_r}\,10^{-9}\text{ ohms} \tag{10}$$

and the inductance,

$$\begin{aligned} L &= \frac{x}{2\,\pi\,f} \\ &= 2\log\frac{l'}{l_r}\,10^{-9}\text{ henrys} \end{aligned} \tag{11}$$

The cosine component of E' is in phase with the current, thus an energy voltage, and gives rise to an effective resistance, the magnetic radiation resistance:

$$r = 4\,\pi\,f\,al'\,10^{-9}\text{ ohms.} \tag{12}$$

Substituting (**2**) into (**15**) gives:

$$r = \frac{8\,\pi^2\,f^2\,l'}{S}\,10^{-9}\text{ ohms.} \tag{13}$$

That is, the radiation resistance is proportional to the distance from the return conductor, and to the square of the frequency, but is independent of size, shape or material of the conductor.

From (**14**) and (**16**) follow as the attenuation constant of magnetic radiation,

$$u_1 = \frac{r}{2\,L} = \frac{4\,\pi\,f^2\,l'}{2\,S\log\dfrac{l'}{l_r}} \tag{14}$$

At a distance l from the conductor, the dielectric or electrostatic field lags behind the voltage (**1**) by angle $a\,l$, thus, per unit length of conductor, is given by,

$$\psi = \Psi \cos(\theta - \beta - \alpha\, l) \qquad \textbf{(15)}$$

The voltage gradient is $2/l$ times the dielectric flux, and the total voltage from conductor to return conductor thus is given by,

$$e = \int_{l_r}^{l'} \frac{2\,\psi}{l}\, d\,l$$

or:

$$E\cos(\theta - \beta) = 2\,\Psi \int_{l_r}^{l'} \frac{\cos(\theta - \beta - a\,l)}{l}\, d\,l$$

$$= 2\,\Psi \left\{ \cos(\theta - \beta) \int_{l_r}^{l'} \frac{\cos a\,l}{l}\, d\,l \right.$$

$$\left. + \sin(\theta - \beta) \int_{l_r}^{l'} \frac{\sin a\,l}{l}\, d\,l \right\} \qquad \textbf{(16)}$$

hence, by (**6**) and (**7**):

$$E\cos(\theta - \beta) = 2\,\Psi \left\{ \log \frac{l'}{l_r} \cos(\theta - \beta) \right.$$

$$\left. + a\,l' \sin(\theta - \beta) \right\} \qquad \textbf{(17)}$$

The dielectric field gives rise to a current in quadrature with the field, the capacity or charging current of the conductor:

$$I_1 = 2\,\pi\, f\, \Psi \qquad \textbf{(18)}$$

and, substituting (**18**) into (**17**), gives,

$$E\cos(\theta - \beta) = \frac{I'}{\pi\, f} \left\{ \log \frac{l'}{l_r} \sin(\theta - \beta) \right.$$

$$\left. + a\,l' \cos(\theta - \beta) \right\} \qquad \textbf{(19)}$$

where the change of the trigonometric functions represents the quadrature relation.

The reactive or sine component of this current I' gives rise to the capacity reactance,

$$x_c = \frac{S^2 \log \dfrac{l'}{l_r}}{\pi f} \, 10^{-9} \text{ ohms} \qquad \textbf{(20)}$$

and the capacity:

$$C = \frac{1}{2\,\pi\, f\, x_c}$$

$$= \frac{10^{-9}}{2\,S^2 \log \dfrac{l'}{l_r}} \text{ farads} \qquad \textbf{(21)}$$

where the factor S^2 reduces from electrostatic to electromagnetic units.

The cosine component of I' is in phase with the voltage, thus an energy current, and gives rise to an effective resistance, the dielectric radiation resistance.

$$r_c = \frac{a\, l'\, S^2}{\pi f} \, 10^{-9} \text{ ohms,} \qquad \textbf{(22)}$$

or, by (**2**):

$$r_c = 2l' \; S \, 10^{-9} \text{ ohms} \qquad \textbf{(23)}$$

If the specific capacity of the medium differs from unity, and is κ, then κ enters as factor in the numerator of C and in the denominator of x_c and r_c.

From (**21**) and (**23**) follow as the attenuation constant of dielectric radiation:

$$u_2 = \frac{g}{2\,C} = \frac{\pi\, f\, r_c}{x_c}$$

$$= \frac{2\,\pi^2 f^2\, l'}{S^2 \log \dfrac{l'}{l_r}} \qquad \textbf{(24)}$$

$$= u_1$$

that is, the dielectric and the magnetic attenuation constant of magnetic radiation are equal; in other words, by electric radiation, the magnetic and the dielectric energy decay at the same rate, and their ratio thus remains constant.

It is interesting to note, that the expressions of inductance L and capacity C, (**11**) and (**21**), are the same as the values of

L and C, calculated without considering the finite velocity of the electric field, that is, are the "low frequency values" of external inductance and capacity. Thus:

As long as the distance of the return conductor is small compared with a quarter wave length, electric radiation due to the finite velocity of the electric field, does not affect or change the values of external inductance L and of capacity C, but causes an energy dissipation by electromagnetic and by dielectric or electrostatic radiation, which is represented by effective resistances. The electromagnetic radiation resistance is a series resistance, proportional to the square of the frequency; the electrostatic resistance is a shunted resistance in series with the capacity. It is independent of the frequency and the power consumed by either resistance thus is proportional to the square of the frequency.

Equations (**6**) and (**7**), and thus the equations (**10**), (**11**), (**13**); (**20**), (**21**), (**23**), of the circuit constants x, L, r; x_c, C, r_c, apply only as long as the distance l' of the return conductor is small compared with a quarter wave length, and with sufficient approximation up to l' = one half of a quarter wave length.

With the return conductor at 6 ft. = 182 cm., the minimum wave length would be $8 \times 182 = 1456$ cm., and the maximum frequency thus:

$$f_0 = \frac{3 \times 10^{10}}{1456} = 20 \text{ million cycles, approx.}$$

With the ground as return, and the conductor 30 ft. above ground, thus the image conductor as equivalent return conductor at 2×30 ft. = 1820 cm. distance, the maximum frequency is:

$$f_0 = \frac{3 \times 10^{10}}{8 \times 1820} = 2 \text{ million cycles, approx.}$$

As seen, the approximations (**6**) and (**7**) apply to practically all industrially important transients, with rare exceptions.

For such high frequencies however, where the distance of the return conductor, l', approaches or exceeds a quarter wave length, or in the case of a conductor without return conductor ($l' = \infty$), such as is approximated by the wireless antenna, or by a lightning discharge to ground, the integrals (**6**) and (**7**) have to be evaluated.

They define new functions:*

$$\int_{l_r}^{l'} \frac{\sin a\,l}{l}\,d\,l = \operatorname{col} a\,l_r - \operatorname{col} a\,l' \qquad \textbf{(25)}$$

$$\int_{l_r}^{l'} \frac{\cos a\,l}{l}\,d\,l = \operatorname{sil} a\,l_r - \operatorname{sil} a\,l' \qquad \textbf{(26)}$$

and, since l_r is always small compared with a quarter wave length, it is:

$$\operatorname{col} a\,l_r = \frac{\pi}{2} \qquad \textbf{(27)}$$

$$\operatorname{sil} a\,l_r = \log \frac{1}{a\,l_r} - 0.5772 \qquad \textbf{(28)}$$

Substituting (**25**), (**26**), (**27**) and (**28**) instead of (**6**) and (**7**), into the previous discussion, gives the final complete equations:

$$(10) \quad x = 4\,\pi\,f \left\{ \log \frac{1}{a\,l_r} - 0.5772 - \operatorname{sil} a\,l' \right\} 10^{-9}$$

$$= 4\,\pi\,f \left\{ \log \frac{S}{2\,\pi\,f\,l_r} - 0.5772 - \operatorname{sil} \frac{2\,\pi\,f\,l'}{S} \right\} 10^{-9} \text{ ohms} \qquad \textbf{(29)}$$

$$(11) \quad L = 2 \left\{ \log \frac{1}{a\,l_r} - 0.5772 - \operatorname{sil} a\,l' \right\} 10^{-9}$$

$$= 2 \left\{ \log \frac{S}{2\,\pi\,f\,l_r} - 0.5772 - \operatorname{sil} \frac{2\,\pi\,f\,l'}{S} \right\} 10^{-9} \text{ henrys} \qquad \textbf{(30)}$$

$$(13) \quad r = 4\,\pi\,f \left\{ \frac{\pi}{2} - \operatorname{col} a\,l' \right\} 10^{-9}$$

$$= 4\,\pi\,f \left\{ \frac{\pi}{2} - \operatorname{col} \frac{2\,\pi\,f\,l'}{S} \right\} 10^{-9} \text{ ohms} \qquad \textbf{(31)}$$

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*Tables of the numerical values of these functions are given in the Appendix to the second edition of "Theory and Calculation of Transient Electric Phenomena."

(20) $$x_e = \frac{S^2}{\pi f} \left\{ \log \frac{1}{a\, l_r} - 0.5772 - \text{sil}\, a\, l' \right\} 10^{-9}$$

$$= \frac{S^2}{\pi f} \left\{ \log \frac{S}{2\,\pi f\, l_r} - 0.5772 - \text{sil}\, \frac{2\,\pi f\, l'}{S} \right\} 10^{-9} \text{ ohms} \qquad (32)$$

(21) $$C = \frac{10^{-9}}{2\, S^2 \left\{ \log \frac{1}{a\, l_r} - 0.5772 - \text{sil}\, a\, l' \right\}}$$

$$= \frac{10^{-9}}{2\, S^2 \left\{ \log \frac{S}{2\,\pi f\, l_r} - 0.5772 - \text{sil}\, \frac{2\,\pi f\, l'}{S} \right\}} \text{ farads} \qquad (33)$$

(23) $$r_e = \frac{S^2}{\pi f} \left\{ \frac{\pi}{2} - \text{col}\, a\, l' \right\} 10^{-9}$$

$$= \frac{S^2}{\pi f} \left\{ \frac{\pi}{2} - \text{col}\, \frac{2\,\pi f\, l'}{S} \right\} 10^{-9} \text{ ohms} \qquad (34)$$

As seen from the tables of col x, the radiation resistances, and thus the energy dissipation by magnetic and dielectric radiation, increase with increasing distance of the return conductor, reach a maximum when the distance of the return conductor is one-half wave length, and then decrease again.

The maximum radiation resistances, at l' = one-half wave length, are:

$$r = 7.41\, \pi f\, 10^{-9}$$
$$= 23.27 f\, 10^{-9} \text{ ohms.} \qquad (35)$$

$$r_e = \frac{1.852\, S^2}{\pi f}\, 10^{-9}$$

$$= \frac{0.531}{f}\, 10^{12} \text{ ohms.} \qquad (36)$$

Substituting $l' = \infty$ into equations (**29**) to (**34**) gives the radiation constants of the conductor without return conductor.

$l = \infty$ gives:

$$\text{sil}\, a\, l' = 0 = \text{col}\, a\, l^1 \qquad (37)$$

thus:

$$(29)\quad x = 4\,\pi\,f \left\{ \log \frac{S}{2\,\pi\,f\,l_r} - 0.5772 \right\} 10^{-9} \text{ ohms} \qquad (\mathbf{38})$$

$$(30)\quad L = 2 \left\{ \log \frac{S}{2\,\pi\,f\,l_r} - 0.5772 \right\} 10^{-9} \text{ henrys} \qquad (\mathbf{39})$$

$$(31)\quad r = 2\,\pi^2 f\,10^{-9} \text{ ohms} \qquad (\mathbf{40})$$

$$(32)\quad x_c = \frac{S^2}{\pi\,f} \left\{ \log \frac{S}{2\,\pi\,f\,l_r} - 0.5772 \right\} 10^{-9} \text{ ohms.} \qquad (\mathbf{41})$$

$$(33)\quad C = \frac{10^{-9}}{2\,S^2 \left\{ \log \dfrac{S}{2\,\pi\,f\,l_r} - 0.5772 \right\}} \text{ farads} \qquad (\mathbf{42})$$

$$(34)\quad r_c = \frac{S^2}{2\,f}\,10^{-9} \text{ ohms} \qquad (\mathbf{43})$$

APPENDIX C

Equations of Electrical Constants

Let: l = length of conductor, cm.
l_r = radius of conductor, cm.
l_1 = circumference of conductor, cm.
l_2 = shortest circumference of conductor, cm.
l' = distance of return conductor
f = frequency, cycles per second
γ = electrical conductivity, mhos per cm^3.
μ = magnetic permeability
$S = 3 \times 10^{10}$ = velocity of radiation in empty space,
it is then, log denoting the natural logarithm:

resistances:

true ohmic resistance (thermal):

$$r_0 = \frac{l}{\gamma\,\pi\,l^2_r} \text{ ohms.}$$

effective resistance of unequal current distribution (thermal):

$$r_1 = \frac{\pi\,l}{l_1} \sqrt{\frac{0.4\,\mu\,f'}{\gamma}}\,10^{-4} \text{ ohms.}$$

effective magnetic radiation resistance:

(a) return conductor at distance l':

$$r_3 = \frac{8\,\pi^2 f^2\,l'\,l}{S}\,10^{-9} \text{ ohms}$$

at extremely high frequencies:

$$r_4 = 4\,\pi f l \left\{ \frac{\pi}{2} - \operatorname{col} \frac{2\,\pi f l'}{S} \right\} 10^{-9} \text{ ohms.}$$

(b) conductor without return conductor:

$$r_2 = 2\,\pi^2 f l\, 10^{-9} \text{ ohms.}$$

effective dielectric radiation (shunted) resistance:[1]

(a) return conductor at distance l':

$$r_c = \frac{2\,l' S}{l}\, 10^{-9} \text{ ohms}$$

at extremely high frequencies:

$$r_c = \frac{S^2}{\pi f l} \left\{ \frac{\pi}{2} - \operatorname{col} \frac{2\,\pi f l'}{S} \right\} 10^{-9} \text{ ohms}$$

(b) conductor without return conductor:

$$r_c = \frac{S}{2 f l}\, 10^{-9} \text{ ohms}$$

reactances:

low frequency internal reactance:

$$x_{10} = \pi f l\, \mu\, 10^{-9} \text{ ohms.}$$

internal reactance of unequal current distribution:

$$x_1 = \frac{\pi l}{l_1} \sqrt{\frac{0.4\,\mu f}{\gamma}}\, 10^{-4} \text{ ohms, } = r_1$$

external reactance:

(a) return conductor at distance l':

$$x_0 = 4\,\pi f l \log \frac{l'}{l_r}\, 10^{-9} = 4\,\pi f l \log \frac{2\,\pi\, l'}{l_2}\, 10^{-9} \text{ ohms}$$

at extremely high frequencies:

$$x_4 = 4\,\pi f l \left\{ \log \frac{S}{2\,\pi f l_r} - 0.5772 - \operatorname{sil} \frac{2\,\pi f l'}{S} \right\} 10^{-9} \text{ ohms}$$

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[1] As shunted resistance and reactance, r_c and x_c are inverse proportional to the length of the conductor l that is, the longer the conductor, the more current is shunted across, and the lower therefor are r_c and x_c. For this reason, the shunt constants usually are given as conductance g and susceptance b. In the present case however, r and x give simpler expressions.

(b) conductor without return conductor:

$$x_2 = 4\,\pi f l \left\{ \log \frac{S}{2\,\pi f l_r} - 0.5772 \right\} 10^{-9} \text{ ohms}$$

shunted capacity reactance:

(a) return conductor at distance l':

$$x_c = \frac{S^2 \log \dfrac{l'}{l_r}}{\pi f l} 10^{-9} = \frac{S^2 \log \dfrac{2\,\pi\, l'}{l_2}}{\pi f l} 10^{-9} \text{ ohms}$$

at extremely high frequencies:

$$x_c = \frac{S^2}{\pi f l} \left\{ \log \frac{S}{2\,\pi f l_r} - 0.5772 - \operatorname{sil} \frac{2\,\pi f l'}{S} \right\} 10^{-9} \text{ ohms.}$$

(b) conductor without return conductor:

$$x_c = \frac{S^2}{\pi f l} \left\{ \log \frac{S}{2\,\pi f l_r} - 0.5772 \right\} 10^{-9} \text{ ohms}$$

inductances:

low frequency internal inductance:

$$L_{10} = \frac{l\,\mu}{2}\, 10^{-9} \text{ henrys}$$

internal inductance of unequal current distribution:

$$L_1 = \frac{l}{l_1} \sqrt{\frac{0.1\mu}{\gamma f}}\, 10^{-4} \text{ henrys}$$

external inductance:

(a) return conductor at distance l':

$$L_0 = 2\,l \log \frac{l'}{l_r} 10^{-9} = 2\,l \log \frac{2\,\pi\, l'}{l_2} 10^{-9} \text{ henrys.}$$

at extremely high frequencies:

$$L_4 = 2\,l \left\{ \log \frac{S}{2\,\pi f l_r} - 0.5772 - \operatorname{sil} \frac{2\,\pi f'\, l'}{S} \right\} 10^{-9} \text{ henrys.}$$

(b) conductor without return conductor:

$$L_2 = 2\,l \left\{ \log \frac{S}{2\,\pi f l_r} - 0.5772 \right\} 10^{-9} \text{ henrys.}$$

capacity:

(a) return conductor at distance l':

$$C_0 = \frac{10^9}{2\,S^2 \log \dfrac{l'}{l_r}} \text{ farads}$$

at extremely high frequencies:

$$C_4 = \frac{10^9}{2\,S^2 \left\{ \log \frac{S}{2\,\pi f\, l_r} - 0.5772 - \operatorname{sil} \frac{2\,\pi f\, l'}{S} \right\}} \text{ farads}$$

(b) conductor without return conductor:

$$C_2 = \frac{10^9}{2\,S^2 \left\{ \log \frac{S}{2\,\pi f\, l_r} - 0.5772 \right\}} \text{ farads}$$

Herefrom then follow the Circuit Constants:

At Low Frequencies: (Machine Frequencies up to 10^3 cycles, approx.)

$$\begin{aligned} r &= r_0 \\ x &= x_{10} + x_0 \\ L &= L_{10} + L_0 \\ C &= C_0 \\ g &= 0 \end{aligned}$$

At Medium Frequencies: (10^3 to 10^5 cycles, approx.)

$$\begin{aligned} r &= r_1 \\ x &= x_1 + x_0 \\ L &= L_1 + L_0 \\ C &= C_0 \\ g &= 0 \end{aligned}$$

At High Frequencies: (10^5 to 10^7 cycles, approx.)

$r = r_1 + r_3$ (with return conductor)
$\quad = r_1 + r_2$ (without return conductor)
$x = x_1 + x_0$ (with return conductor)
$\quad = x_1 + x_2$ (without return conductor)
$L = L_1 + L_0$ (with return conductor)
$\quad = L_1 + L_2$ (without return conductor)
$C = C_0$ (with return conductor)
$\quad = C_2$ (without return conductor)
(approximately, or represented by x_c and r_c)
g represented by r_c and x_c:

$$g = \frac{r_c}{r^2_c + x^2_c}\ ;\ b = \frac{x_c}{r^2_c + x^2_c} = 2\,\pi f C$$

At Extremely High Frequencies: (above 10^7 cycles, approx.)

$r = r_1 + r_4$ (with return conducter)
$\quad = r_1 + r_2$ (without return conductor)
$x = x_1 + x_4$ (with return conductor)
$\quad = x_1 + x_2$ (without return conductor)

C and g represented by r_c and x_c, thus:

$$g = \frac{r_c}{r_c^2 + x_c^2}$$

$$C = \frac{x_c}{2\,\pi\, f\,(r_c^2 + x_c^2)}$$

From these follow the Derived Circuit Constants:
Magnetic Attenuation:

$$u_1 = \frac{r}{2\,L}$$

Dielectric Attenuation:
Usually zero at low and medium frequencies,

$$u_2 = \frac{g}{2\,C} = \frac{\pi\, f\, r_c}{x_c}$$

at high and very high frequencies.
Attenuation Constant:

$$u = u_1 + u_2 = \frac{1}{2}\left(\frac{r}{L} + \frac{g}{C}\right)$$

Series Power Factor:

$$\cos\,\omega = \frac{r}{\sqrt{r^2 + x^2}}$$

Shunt Power Factor:
Zero at low and medium frequencies,

$$\cos\,\omega_c = \frac{r_c}{\sqrt{r_c^2 + x_c^2}}$$

at high and very high frequencies.
Duration of Oscillation:[1]

$$t_0 = \frac{1}{u} \text{ seconds}$$

$$N_0 = \frac{f}{u} \text{ cycles}$$

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[*] Under "Duration" of a transient is understood the time (or the number of cycles), which the transient would last, that is, the time in which it would expend its energy, if continuing at its initial intensity. With a simple exponential transient, this is the time during which it decreases to $\frac{1}{\epsilon}$ or 36.8 per cent of its initial value. It decreases to one-tenth of its initial value in 2.3 times this time.

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(*Subject to final revision for the Transactions.*)

FUSION IN ARC WELDING

BY O. H. ESCHHOLZ

ABSTRACT OF PAPER

Although welding literature is replete with discussions of applications, little information is available descriptive either of non-destructive inspection methods or of the process of metallic electrode arc welding. This paper calls attention to such characteristics as penetration and overlap, peculiar to this process, which facilitate visual inspection and discusses briefly the effect of arc length, welding procedure, electrode material, arc current and electrode diameter upon these characteristics.

THE physical characteristics of a weld are admittedly determined chiefly by the degree of fusion secured between adjacent metals. In the production of welds by the metallic electrode process, a fair estimate of the fusion may be obtained by an examination of the surface of the deposited metal and the depth of the arc crater formed when welding at normal speed. These observations give an adequate indication of the two prime characteristics of fusion—penetration and over-lap—which, however, are definitely revealed only on exposing a section through the zone fusion.

Fig. 1 illustrates the union between a layer of metal deposited from a low carbon steel electrode upon a low carbon steel plate. The line of demarcation between the plate and deposit indicates the zone of fusion, the polished and etched surface of the deposited material presenting a different appearance, due to its crystalline structure, from that of the plate material. Two characteristics are at once apparent; a penetration of the deposited metal into the plate metal over almost the entire width of the layer, and a slight overlapping upon the plates without fusion of the extreme edges of the deposit. The penetration is due to liquefying of the plate metal by the energy absorbed from the arc as well as that absorbed from the molten deposit.

At the center of the deposit, where both effects are present,

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the penetration is greatest; at the extreme edges, however, where the deposit has overflowed the area included by the arc crater, the energy liberated on cooling is insufficient to melt the plate metal and the deposit congeals without fusing to it. It is typical of such overlapping that the edges of the deposit are well rounded, a distinct gap often existing between the plate and edge of deposit. The convex surface of the deposit thus forms a re-entrant angle with the plate edge. To insure satisfactory fusion a proper degree of penetration should be obtained with no overlap.

PENETRATION

Fig. 2 illustrates a section through the crater obtained on breaking an arc during the process of depositing a layer of metal on a steel plate. It may be observed that the depth of the crater depression is comparable to the depth of penetration of the deposited metal below the plate surface. A simple visual indication is, therefore, available during the welding operation for gaging the penetration.

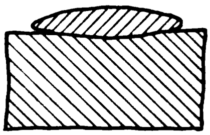


FIG. 4 — EXTREME OVERLAP OBTAINED ON WELDING WITH AN ELECTRODE OF LOWER MELTING POINT THAN THAT OF THE PLATE METAL

OVERLAP

The convex edges of the deposit shown in Fig. 2, particularly evident at the right of each view, would lead one to expect an appreciable overlap. This is disclosed on a careful inspection of the sections. Fig. 3 illustrates a surface contour with no overlap. This condition is usually typified by the absence of even the smallest re-entrant angle, an intimate contact between plate and deposit being secured, the junction between the two metals often forming a concave surface.

A condition of extreme overlap is shown in Fig. 4. This is typical of a low melting point electrode or of too great speed of arc travel. The convex deposit edge and the re-entrant angle between it and the plate are pronounced.

ARC LENGTH

The effect on fusion of arc length has been discussed at considerable length by welding engineers. Some assert that better fusion is secured for a given arc current with a long arc than with a short arc, due to the greater amount of energy

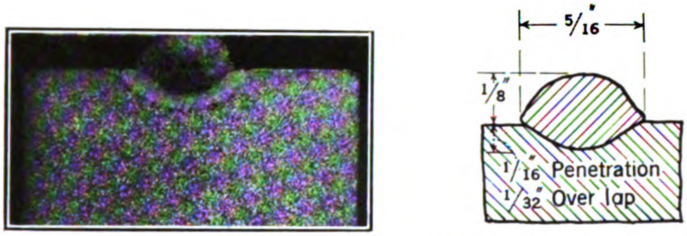


FIG. 1—SECTION THROUGH A LAYER OF ELECTRODE MATERIAL DEPOSITED ON A MILD STEEL PLATE—WHEN USING A SHORT ARC AND A PROPER WELDING CURRENT—SHOWING DEGREE OF PENETRATION AND EXTENT OF OVERLAP

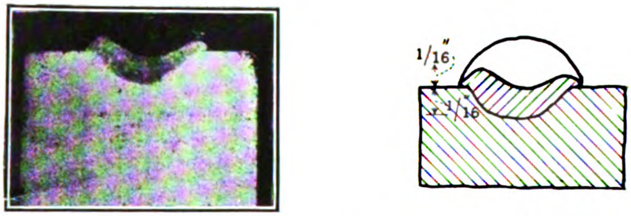


FIG. 2—SECTION THROUGH THE CRATER REMAINING ON INTERRUPTING ARC CURRENT SHOWING THE COMPARABLE DEPTH OF CRATER DEPRESSION AND DEPOSIT PENETRATION

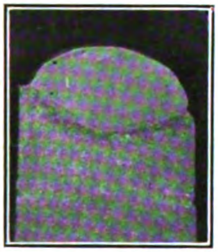


FIG. 3—ABSENCE OF OVERLAP WHEN DEPOSITING METAL OF A HIGH MELTING POINT ON A PLATE OF LOW MELTING POINT

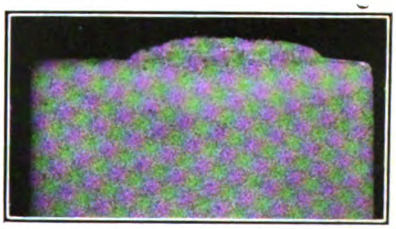


FIG. 5—CHARACTERISTIC SECTION OF DEPOSITS OBTAINED WITH A LONG ARC—INDICATING EXCESSIVE OVERLAP WITH PRACTICALLY NO PENETRATION

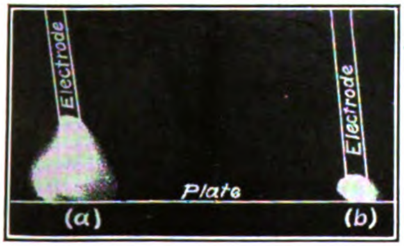
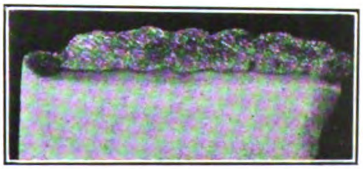


FIG. 6
A—ILLUSTRATING THE EXPOSURE OF NEW METAL RESULTING ON HOLDING A LONG ARC AND THE PROTECTION OBTAINED
B—FROM THE ENVELOPING GASES WITH A SHORT ARC



[ESCHHOLZ]

FIG. 9—SECTION THROUGH THE CENTER OF A DEPOSITED LAYER IN THE DIRECTION OF FORMING DEPOSIT—SHOWING DEGREE OF PENETRATION WITH NO UNFUSED AREAS

absorbed by the arc; others have stated that the degree of fusion is dependent solely on the arc current and, of course, the thermal characteristics of the metal welded. For a given arc current it has been the author's experience that fusion is not improved with increase in arc length, that the best weld characteristics are obtained when holding a short arc, not longer than ⅛ in. and preferably about $\frac{1}{16}$ in. With a given arc length the ease of securing complete fusion increases with arc current until a maximum value is reached beyond which further increase results in a weakened weld structure.

Figs. 1 and 5 are typical of sections through deposits formed with a short and a long arc, respectively, the arc current being approximately the same in each instance. With a short arc the plate metal is liquefied by the energy required to maintain the arc crater, by that conducted from the arc flame in constant intimate contact with the plate and by the energy radiated from the arc stream and electrode terminals, as well as by that absorbed from the molten electrode deposit. When the molten material passes through a short arc it is quite completely enveloped by hot gases and suffers but a slight loss in temperature before being deposited. Upon drawing a long arc the air currents in its vicinity blow the arc stream and arc flame about violently, so that it is difficult to maintain the plate terminal of the arc in a given position long enough to effect sufficient penetration. Moreover, the energy absorbed from the arc stream and electrode terminal becomes practically negligible, due to the greater diffusion of the radiation in the region of the arc plate terminal, while the energy absorbed from the molten metal is decreased because of the loss in temperature the deposit has sustained in transition. Some conception of the appearance of short and long arc lengths may be obtained from Fig. 6.

WELDING PROCEDURE

The extreme condition of no overlap is difficult to secure when depositing a single layer of electrode metal upon the usual low-carbon steel plate. For most purposes a slight overlap, such as is indicated in Fig. 1, is permissible in single layers as a simple procedure of depositing the subsequent layers will fuse the overlapped areas.

Fig. 7 illustrates the characteristic penetration and overlap when parallel abutting layers are formed. The minimum overlap for this condition will approach $\frac{1}{16}$ in. per layer. If the width of a layer is increased by weaving the electrode back and forth the percentage overlap will be decreased. However, it may be eliminated by the simple expedient of always overlapping adjacent layers as shown in Fig. 8. On forming the second tier of deposits the same precaution should be taken to prevent unfused zones. Fig. 9 shows a typical section through the center of a layer. It may be noted that although the depth of penetration varies somewhat, due to the speed of arc travel and unavoidable variation in arc length, good fusion has been secured between the plate and deposit along the entire length of the deposit.

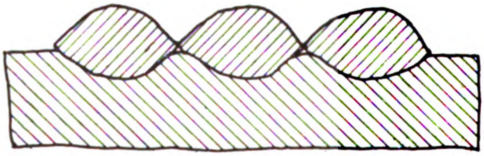


FIG. 7—FUSION OBTAINED ON ABUTTING PARALLEL DEPOSITS

Since the choice of electrode material, arc current and electrode diameter largely determine, with a given manipulative skill and welding procedure, the depth of arc crater and deposit contour, a brief discussion follows of such characteristics which affect fusion between the deposit and plate metals.

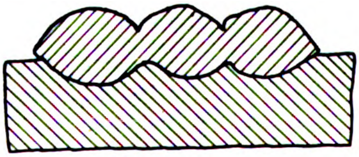


FIG. 8—FUSION SECURED WHEN PARALLEL DEPOSITS ARE OVERLAPPED

ELECTRODE MATERIAL

To minimize the occurrence of unfused areas, the melting point of the electrode metal should exceed that of the plate metal. Fig. 1 illustrates the fusion obtained with the melting points approximately equal, (0.18 per cent carbon, 1510 deg. cent. approx.), Fig. 3 that secured with a greater melting point for the electrode (0.18 per cent carbon, 1510 deg. cent. approx.) than for the plate (3 per cent carbon, 1280 deg. cent. approx.)

and Fig. 4 that obtained with a lower electrode melting point (1.1 per cent carbon, 1440 deg. cent. approx.) The melting point of most weldable steels may be gaged with sufficient accuracy for welding purposes by the carbon content as shown in Fig. 10. The usual additions of other alloying ingredients reduce the melting point a negligible amount.

While pure iron possesses the highest melting point, its use is not advisable since excessive oxidation of the vaporized metal occurs. However, a commercially pure iron alloyed with about 0.18 per cent carbon and 0.5 per cent manganese greatly reduces the oxidation, and improves the ease of manipulation without an appreciable sacrifice in melting point. For most purposes the use of this electrode gives a reasonable minimum overlap.

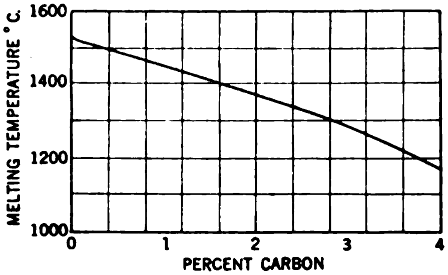


FIG. 10—CHANGE IN MELTING POINT OF IRON ALLOYED WITH VARIOUS AMOUNTS OF CARBON

Under exceptional conditions such as high thermal capacity of weld, or overhead welding with a low current, the overlap may be excessive even when using this electrode, it is customary then to preheat the object to be welded or to adopt a welding procedure which utilizes the thermal energy from preliminary welding operations to raise the temperature of the object welded.

ARC CURRENT

For a given plate thickness the welding current will vary with the type of weld scarf, cleanliness of surface, thermal capacity, and conductivity of the metal, and position of plate with respect to the welder. The values shown in Fig. 11 apply only to clean, butt-welded plates, single V, scarfed to 90 deg., supported in a horizontal position, below welder, in poor thermal contact with any metal of high thermal capacity. The fusion obtained with too low and too high arc currents is shown in Fig. 12. In Fig. 12A the overlap is excessive and the penetration unsatisfactory because of the small amount of energy applied at the arc crater. In Fig. 12B the excessive energy consumption at the plate arc terminal produces excessive penetration, a further increase in current permitting cutting through the plate.

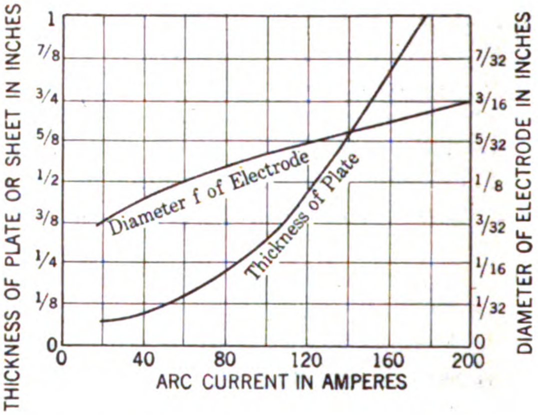
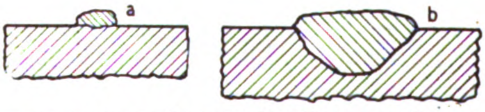


Fig. 11—Approximate Values of Arc Current on Welding Under Conditions of Low Thermal Capacity for Weld

Fig. 13 indicates approximately the effect of variation of arc current on fusion and therefore on weld strength for (a) skilled and (b) unskilled welders. Weld structures are occasionally encountered in which variations in thermal capacity and plate temperature necessitate changes in arc current if complete fusion is to be secured. Observations of the deposit contour and crater depth usually serve to indicate to the operator when such changes are advisable.



A–Fusion Secured with too Low an Arc Current–Excessive Overlap
B–With too High an Arc Current—Excessive Penetration
Fig. 12

Electrode Diameter

A close adjustment of electrode diameter to arc current is not essential. For miscellaneous direct current welding the densities usually fall within a range of 7000 to 10,000 amperes per square inch, if an 0.18 per cent carbon steel electrode is used. However, whenever practicable, the author prefers a closer range of 8000 to 9000 amperes per square inch. With too great an electrode diameter for a given current, the arc becomes more unstable, increasing the manipulative skill required and decreasing the rate of depositing electrode material. Too small a diameter causes a deposition of electrode material before the plate has been properly liquefied; it also results in overheating and softening of electrode which increases the skill required to prevent the electrode from "freezing" to the plate. With the correct diameter the electrode material is sprayed in a regular stream at a rate which will insure maximum welding speed consistent with good fusion.

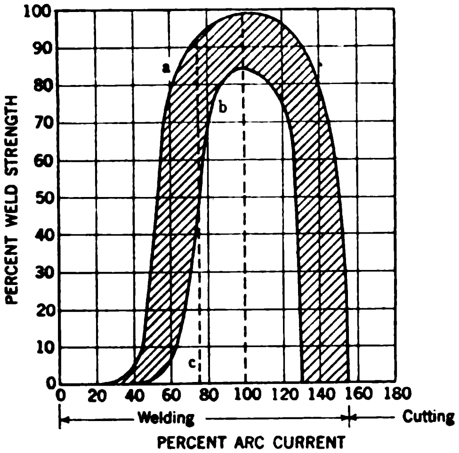


FIG. 13—APPROXIMATE CHANGE IN WELD STRENGTH WITH CHANGE IN ARC CURRENT, FOR A—SKILLED, AND B—UNSKILLED WELDERS

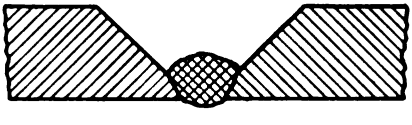


FIG. 14—SECTION THROUGH BUTT WELDED PLATE SHOWING GOOD FUSION AT 150 ARC AMPERES

Example. The characteristics of fusion and the effect of a control of the conditions which govern them may be summarized in comparing the procedure for making butt and lap welds.

In butt welding ½-in. low-carbon steel plates, scarfed as shown in Fig. 14, a $^5/_{32}$-in. diameter welding electrode containing approximately 0.18 per cent carbon, 0.5 per cent manganese, would preferably be used with an arc current of approximately 150 amperes. With moderate skill, the strength of weld should approximate 90 per cent that of the plate. If the same current and electrode diameter are used in welding the lap joint formed from ½ in. plates shown in Fig. 15, poor fusion will be obtained owing to the increased thermal capacity of the abutting sections. As shown in Fig. 15 the penetration will be too slight and the overlap excessive, similar to the case shown in Fig. 12. In fact, sections through completed lap joints most invariably show that in forming the first deposit, which is the most important, even expert welders tend to penetrate only one side of the weld scarf with resultant overlap on the other. Breakdown tests of lap joints have plainly shown failure due to this cause.

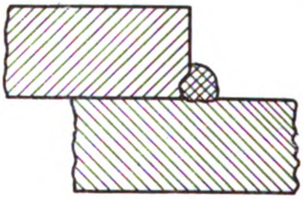


Fig. 15—Section Through Lap Weld—Plate, Arc Current, Electrode Diameter Same as for Fig. 11—Showing Poor Fusion due to Increased Thermal Capacity

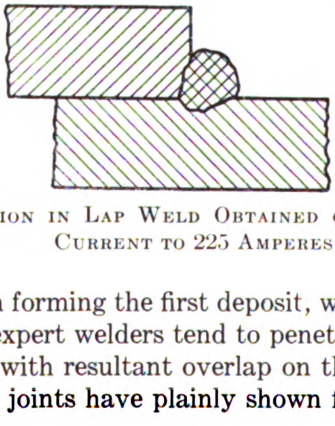


Fig. 16—Good Fusion in Lap Weld Obtained on Increasing Arc Current to 225 Amperes

To secure complete fusion on both faces of the joint it is necessary to increase the arc current and with it the electrode diameter. For the condition shown in Fig. 16 an arc current of 225 amperes and an electrode diameter of $\frac{3}{16}$ in. was found to produce complete fusion, facilitate electrode manipulation and increase rate of electrode deposition.

CONCLUSION

The fusion obtained in arc-welded joints between the plate and deposit metals is determined by the penetration of the deposit metal into the plate metal and the overlap of the edge of the deposit layer on the plate. The penetration is comparable to the depth of arc crater as observed by the welder when moving the arc terminal over the plate with uniform velocity, and the overlap is indicated by the contour of the surface of the congealed deposit in the region adjacent to the material welded. For most welds a crater depression of $\frac{1}{16}$ in. will give the desired penetration while a contour which does not show a re-entrant angle between plate and deposit indicates an overlap per layer of approximately $^1/_{32}$ in. or less.

Presented at the 7th Midwinter Convention of the American Institute of Electrical Engineers, New York, February 19, 1919.

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WELDING AS A PROCESS IN SHIP CONSTRUCTION

BY S. V. GOODALL

ABSTRACT OF PAPER

The paper points to the necessity for a reduction in the cost of shipbuilding, and as riveting is one of the most expensive items of construction the substitution of welding for riveting would decrease the cost of construction considerably. A brief review is given of what has been done in substituting welding for riveting, and to the limited extent to which electric welding has been tried it has been found successful. Lloyd's Register is prepared to classify electrically-welded vessels subject to certain provisions, but shipbuilders have not as yet adopted welding to a large extent for the reason, in the author's opinion, that they know that welds are lacking in uniformity and it is impossible to tell when a joint is good or bad. The author believes that the correct method of approaching the problem of electric welding is first to obtain workmen who are thoroughly trained and skilled and the suggestion is made that only certified men should be employed at this work. From the welding of minor parts the process could be advanced to more important members until eventually a ship would be produced in which both the processes of welding and riveting would be utilized in whatever proportions would attain maximum economy of construction.

DURING the war, economy of time in the production of all that was needed to terminate hostilities successfully was of paramount importance. Economy in first cost and maintenance was relatively unimportant. If the production of a ship, an aeroplane, a tank or any implement of war could hasten the end by a single day it was more economical, in the long run, to place that implement on service today instead of tomorrow, even at a somewhat higher cost, for the shortening of the struggle by that single day meant a saving of many lives and millions of dollars. But besides being called upon to save time the engineer was forced to economize in labor and to use unskilled workmen. During the war gas welding and electric welding have been enormously developed as processes in the manufacture of munitions of all kinds. It goes without saying, therefore, that in these processes engineers found a means of saving time and labor.

Now that hostilities have ceased, economy in first cost and

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maintenance becomes once again of primary importance, economy of time and labor being of value only in so far as it results in cheaper production. This is particularly true of shipbuilding. Every shipbuilder should now carefully review the various items of cost in the production of a ship, and while he may devote his energies to a reduction all round, he will, if he be wise, give greatest attention to a reduction in the cost of the most expensive of those items. Riveting is this most expensive item. It has been estimated that the labor cost of riveting is about 40 per cent of the total labor cost of building the structure of a steel cargo carrier, while the labor cost of shopwork on structural material is about 15 to 20 per cent. During the past few years considerable attention has been given to improvements in shopwork and it is unlikely that much economy can be effected in this direction. Can anything be done to lower the cost of riveting? The advocates of welding reply "Yes, by a wide substitution of welding for riveting." This is a claim that should not be lightly placed on one side but carefully and critically examined by all shipbuilders. To offer some slight assistance in that examination this paper has been prepared.

Gas welding has been used in shipyards for many years, resulting in economy in the production of staple angles and similar smith work. It has found a wide field in the construction of light fittings, being more particularly of value for thin work than for heavy plating. As it may be considered that gas welding has now found its level as a shipbuilding process, this subject is not enlarged upon; the little that is said must not be taken as a measure of its importance.

Electric welding as a science and art has been dealt with at this meeting. As a process in shipbuilding much literature on the subject already exists, the most comprehensive papers known to the author being that by Mr. W. S. Abell, Chief Ship Surveyor of Lloyd's Register, read before the British North East Coast Institution of Shipbuilders and Engineers at Newcastle in November, 1918, and that by Mr. H. Jasper Cox, read before the Society of Naval Architects and Marine Engineers at Philadelphia in the same month. The author makes no attempt, even if he were capable of doing so, of giving such detailed particulars of the subjects as can be found in these and other papers, but he does attempt to speak, as a shipbuilder to shipbuilders, plainly and impartially, without extravagant claims, and with some little knowledge of experience so far obtained, on the present position of the process and the policy which should be adopted, looking towards the future.

It is very well known that electric welding has been of great value on repair work, particularly during the war. Ships that would otherwise have been laid up for weeks while new castings were obtained, old plates removed and replaced by new, &c., &c., have been rapidly repaired and returned to service. If the ship repairer finds a process of such value the shipbuilder should at least inquire whether it would not be of some value to him.

The Classification Societies have sanctioned the use of electric welding for a considerable amount of work of little importance so far as structural strength is concerned. The Welding Committee of the Emergency Fleet Corporation has found by actual experience that a labor saving of at least 60 per cent results from the substitution of arc welding for riveting on these minor parts of a ship; and Mr. J. H. Anderton has estimated that a saving in time of 70 per cent was effected at Hog Island.

Lloyd's Register of Shipbuilding is prepared to classify an electrically welded vessel, subject to the notations, "Experimental" and "Electrically Welded," and provided the builders conform to certain rules. This decision was reached after an extensive and exhaustive series of trials. Before any electric welding system can be employed on a vessel which Lloyd's will classify, specimens welded according to that system must satisfy tests, which, at first sight, appear almost prohibitive in their severity, but an electrically welded ship is now under construction at Cammell Laird's, England, to be classified by Lloyd's, who have approved the employment of the Quasi-Arc Company's system in its construction. This is a small vessel about 150 feet long, with plating generally 3/8 to 1/2 inch in thickness.

Electric welding work carried out by the British Admiralty has been described in a paper read by the author before the Engineers' Club of Philadelphia, in July, 1918. Since that time valuable experience with this work on service has been obtained. The arc welded barge has been satisfactory. The cost of material, electric current and labor for this vessel was £301 ($1463) as compared with £389 ($1892) for the cost of riveting, caulking and drilling on a similar barge constructed at the same yard. The vessel was designed to be rivetless as a demonstration of arc welding; it was found that greater economy would result if certain parts such as beams to frames, floor plates to angles, etc., were riveted.

As the plating of this barge is thin and the stresses to which it is subjected are not comparable to those which a large seagoing ship is called upon to withstand, greater interest attaches to experience with other British ships in which arc welding has been employed by the Admiralty, particularly to those where the work has been comparatively heavy. It must be said at once that failures of welded joints have been reported, although the number of such failures has not been large considering the amount of work that has been done, the lack of experience, the dearth of skilled operators, and the radical change in method. The Admiralty authorities, however, consider it wise, pending further experience, to defer the adoption of electric welding for those parts of the structure subjected to high complex stresses unless the work can be so tested as to demonstrate exactly that such stresses can be safely carried.

Lap welding has been more satisfactory than butt welding and the latter has been, for the present, discarded for all important work where the plating is 3/8 inch or more in thickness. It is hoped that this situation will not last long, for it is in butt welding that the greatest gain from the use of this process may be expected, and lap joints necessitate a certain amount of overhead welding which is difficult and unreliable.

While the above briefly sums up the present position of electric welding as a process in shipbuilding it may be fairly asked why—if the Classification Societies permit the process on minor parts; if Lloyd's are prepared, subject to certain conditions to classify an electrically welded ship; if the British Admiralty has employed the process to a considerable extent; if American railroads have used welding extensively on locomotives—why has not electric welding been adopted in American shipyards to a greater extent than it has been up to the present? There is no doubt that during the war, shipbuilders in the United States were too hard pressed to be able to give much time and thought to the development of an entirely new process in ship construction. This is one reason. Inate conservatism is another. But the real reason, in the author's opinion, is that shipbuilders know that, at present, welds are lacking in uniformity, and it is not yet possible to tell when the welded joint is good or bad. Hence they hang back and the author commends their wisdom.

It is far better that the first ocean-going electrically welded ship should be on service three years hence with every joint sufficiently sound—universally accepted as a thorough success—than that it should be at the bottom of the sea tomorrow because, while 999 joints were sound, one went astray.

How can this certainty that every joint will be efficient be ensured? While the electrical engineer and the metallurgist can assist the shipbuilder to solve this problem, there is much that he himself can do.

In the first place he must realize the importance of employing only thoroughly skilled and experienced workmen and he should call in the manufacturers of electric welding apparatus to assist him. The latter, for their own protection and the welfare of the industry on which they rely, should see to it that no ship should be allowed to be built with some of the thoroughly rotten work done by absolutely unskilled welders that the author has seen in this country. It is strongly urged that steps should be taken at once to establish welding as a skilled trade and only certified men should be allowed to be employed. All the reports that have been seen on good and bad welds lay stress upon the fact that, in general, defects are mechanical and not an inherent feature of the process. Skilled men working under an experienced foreman would know, for example, that clean surfaces are necessary for good work, they would quickly learn what types of joint are made with ease, in what portions of a ship welding is cheap or where it is unreliable, and from their ranks should be drawn the draughtsmen who will design in detail the welded vessel of the future. The Electric Welding Committee of the Emergency Fleet Corporation has spent much time and thought on the attempt to discover a practical non-destructive method of testing welds. While such a method of testing would be very valuable, it is the author's opinion, that when only welders of proved skill are employed under experienced supervision, such tests would be no more necessary than a shear test on every rivet of a riveted ship; but, so long as such welders are not available the shipbuilder will look askance at a process that may be good generally but may have weak spots of which he is ignorant.

Secondly, after he has trained a reliable staff of welders on work of minor importance the shipbuilder must devote his attention to the best method of assembly of large parts, so that he may feel reasonably sure that every joint of the finished structure possesses the qualities which his welders can with certainty produce in test pieces. From the very outset it has been realized that this is a difficult problem which can be solved only by patient trial and experience. Present opinion at the British Admiralty is that the only satisfactory method is by the use of closing bolts as for riveted joints. In the case of the Richborough barge a certain amount of buckling resulted on the outboard edge of the garboard strakes after these plates had been welded to the keel plates, but this was removed when the bilge plates were put into position and bolted up. In the heavier work it may be that, buckling of plates being impossible, the internal stresses set up in welding were the causes of the failures that occurred. It is understood that this method is being adopted at Cammell Laird's but, again the plating of this vessel is not very heavy and it is definitely known that this feature received most careful consideration from the very beginning. In the author's opinion this difficulty is by no means insuperable. Its existence should spur on the progressive shipbuilder, for when he has solved the problem, by that much will he be ahead of his competitors.

In the third place it appears to be the fact that shipbuilding steel in Great Britain is more adapted to welding than shipbuilding steel in this country, and the former is also more regular in its qualities. If shipbuilders are satisfied that such is the case and are also convinced that electric welding has a great future in ship construction, they should take concerted action to ensure that steel producers supply the material best suited to their purpose.

So far the author has urged a careful survey of the possibilities of welding as a substitute for riveting only on the ground that the latter is the most costly item of labor on structural work and it behooves the shipbuilder to reduce that cost. But there are other advantages incidental to welding that must not be overlooked. A sound arc-welded joint is necessarily watertight and once such a joint with known efficiency can be made with certainty caulking is eliminated and the work of water-testing made easier. It must be admitted that, so far, the advantages anticipated in this direction have not been fully realized, but that they will be realized is only a matter of time, and it has already been fully demonstrated that welded joints, being stiffer, stand up better under test and there is no breaking away of the caulk such as is sometimes experienced with riveted connections under water pressure. Another advantage is a saving in steel due to the absence of rivet heads and the smaller width of laps and butt straps. Some advocates of welding claim that the labor of marking off, punching and assembling will be much reduced, more particularly by the adoption of spot-welding, but the author is bound to say that at present he is not a convert to the adoption of spot-welding for heavy ship work, it is his opinion that there are many difficulties ahead for those shipbuilders who attempt this form of welding and until those difficulties have been fairly and squarely met he hesitates to affirm that spot-welding will be found a valuable process in ship construction.

In conclusion, it is desired once again to place the subject before the shipbuilder in this light. The cost of ship construction must be reduced. A reduction in riveting is the most fruitful field for economy. Electric welding as a substitute has been tried to a limited extent and found successful. Classification Societies are prepared to accept the process, though at present the only vessels built or under construction are small. There are difficulties ahead but they do not appear insuperable. The best line of approach appears to be to build up a staff of thoroughly skilled welders, to gain experience by the adoption of welding on minor parts, to proceed cautiously in the extension of the process to more important members, not to expect a great saving in time and cost immediately, but to persevere, not necessarily towards the rivetless ship but towards a vessel in which the employment of both processes of riveting and welding is so adjusted that more riveting or more welding could only be done at greater cost.

Presented at the 7th Midwinter Convention of the American Institute of Electrical Engineers, New York, February 21, 1919.

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(*Subject to final revision for the Transactions*)

RADIO TELEPHONY

BY E. B. CRAFT AND E. H. COLPITTS

Abstract of Paper

This paper is divided into two parts. The first part describes the development of the art of radio telephony by the American Telephone and Telegraph Company and the Western Electric Company to the accomplishment of trans-atlantic telephony, followed by demonstrations of the use of radio telephony between ships and of methods of connecting radio and wire telephone systems. This first part covers work principally of an engineering research nature, the most important problems being the development of systems of generation, modulation, transmission and reception of radio telephone signals.

The second part is concerned almost entirely with the work of producing radio telephone and allied apparatus for the Army and Navy in the late war. The major problem of the second part was the design of light and compact sets which could be produced rapidly and in large numbers, for the main features of the generating, modulating and receiving systems were already well understood.

Historical

RADIO telegraphy has aroused so much popular interest that the main facts of its development to a commercial stage are known to every engineer and to many laymen. A detailed history of the growth of the art is therefore unnecessary in this paper and it is only for the sake of securing the proper point of view for a description of some recent developments in radio telephony that a short sketch of the fundamental principles involved will be presented. The work of Lodge, Marconi, Braun, Fessenden, Fleming, De Forest and many others is described in books written with this professed purpose; in fact a book of considerable dimensions is required to do justice to the historical side of the subject. These remarks are made because the present paper is concerned almost entirely with the work of the Bell Telephone System in radio telephony and little attempt is made to trace to their ultimate origins all the ideas which have entered into the building of the structure as it is at present.

Electromagnetic ether waves of "radio" frequency were

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first intentionally produced and studied by Hertz, who was guided by the electromagnetic equations of Maxwell, constructed twenty years earlier, which predicted electromagnetic wave propagation and the identity of light and electromagnetic radiation. Hertz succeeded in reflecting, refracting and polarizing his waves and in producing interference. The waves were generated by successive disruptive discharges of a condenser formed by two halves of an extended system, or oscillator, and were therefore damped waves occurring in trains. At each discharge a damped oscillatory current flowed to and fro along the oscillator and consequently set up outside the oscillator variable electric and magnetic states which, according to Maxwell's theory, were propagated as waves to remote regions. They were detected by means of a secondary circuit consisting of a nearly complete conducting ring broken by a minute spark gap.

This was the first radio telegraph system, and although Hertz was not concerned with any immediately practical consequences of his method of producing electrical waves, others were quick to see the commercial possibilities. Passing over the very extensive body of scientific work which was started by the researches of Hertz, the next notable achievements were the discovery by Braun of the coherer for making the waves evident, and the invention by Marconi of the present form of antenna which allows the radiation of large power by long waves. These two steps undoubtedly made radio telegraphy a commercial possibility.

Because of the light which is thereby thrown upon subsequent efforts, it is worth while to examine the situation as it existed at that time. Trains of damped waves were produced by the charging of the oscillator system to a high voltage and allowing an oscillatory discharge to take place after each charge. The charges occurred with a frequency which produced audible sounds while the radiated waves were damped out in a rather small number of oscillations. As a result a graph of the wave amplitude would show a succession of violent and rapidly damped disturbances separated by many periods of no disturbance. This method of generation had two effects: first the average power radiated could be made large only by greatly increasing the amplitude of each separate train. This was limited by the voltage which could be allowed on the antenna and associated apparatus. Secondly, a damped wave differs so much from a simple harmonic wave that sharp tuning was impossible and the advantages known to attend its use could not be realized. These difficulties could both be overcome if a sustained wave generator of sufficient power were available; consequently this was the most important technical problem at this time and resulted finally in the development of the high frequency alternator and the arc generator.

In the meantime it had been found that bodies, such as crystals, having partial unilateral conductivity, could be used in connection with a telephone receiver to make the signals audible. In this case what was heard was the note produced by the succession of wave trains, the effect of the crystals being to rectify the received current. The rectified high frequency current varied sufficiently slowly to produce in the telephone an audible sound which continued as long as the key at the sending station was depressed. It is not necessary that the detector be completely unilateral, but only that an applied voltage shall produce a greater current when acting in one sense than when acting in the other. It was soon found that this method of reception employing a telephone receiver and rectifier or detector was far better than that using a coherer, partly because of the greater sensitiveness, but more fundamentally because reception of an audible note by ear allows greater opportunities for discriminating against disturbances.

But with the advent of "continuous" or sustained waves, such a method could not be used without modification, because the rectified current in the telephone receiver was either zero (when the sending key was open) or constant and equal to the average value of the rectified current when the key was closed. Such a flat-topped wave of telegraph frequency produces no audible sound in a telephone receiver except at the make and break. Two solutions of the problem thus presented were given. The first consists in breaking up the received wave into groups at such a rate that the group frequency is in the audible range. This was done by means of a commutator. The other solution, which is extremely elegant and useful, consists in superposing upon the received signal at the receiving station a locally generated wave of frequency slightly different from that of the received signal. Beats are thereby produced which are of audible frequency, and by rectifying this composite wave the current in the telephone is made to vary at any frequency desired. Since the local oscillator is not required to furnish an appreciable amount of power it may be small and may, in fact, be combined with the tuning circuit of the receiver. A more important advantage is that the signals are amplified by this "heterodyne" method of receiving.

This brief sketch brings us to the early attempts at radio telephony. It was realized at an early date that a crystal rectifier, or any similar detector, in combination with a telephone, would produce in the telephone currents whose amplitudes varied approximately as the amplitude of the received high frequency wave; consequently if the amplitude of this wave could be varied at the transmitting station in accordance with speech, radio telephony would be possible. The receiving apparatus was therefore in existence and all that was needed was a means of varying the amplitude of the transmitted wave, that is, the amplitude of the current in the transmitting antenna. Now, in wire telephony, the amplitude of a direct or alternating current is so varied by means of a microphone, and this device was tried for radio telephony, the method being to insert a microphone, or a combination of them, in some part of the antenna circuit traversed by high-frequency currents. This attempt was handicapped because of the fact that microphones, even when specially designed, cannot easily be made to carry large currents and still function properly. Their use, however, suggested that it might be possible to devise somewhat similar apparatus, and as a result there appeared numerous voice-operated resistance-varying devices. Using methods of this kind considerable success was attained; thus in 1912 Vanni succeeded in telephoning 1000 kilometers.

FUNDAMENTAL PRINCIPLES

In order, however, to understand the nature of the telephone problem, a short discussion is necessary to make clear what are some of the limiting factors in the transmission and reception of speech. Consider first the simplest case of the familiar wire telephone system, which will be taken as a speech-actuated microphone, a battery and an electromagnet in series. A certain current, I, flows in this series circuit and produces a pull, proportional to the square of the magnetic field strength, and consequently proportional to I^2, upon the armature. Now let the microphone be actuated and suppose its design is so good that a sinusoidal variation in air pressure produces a sinusoidal variation in the *carrier current* I. Then the result of singing a pure note of frequency $n/2\pi$ into the microphone will be to produce a current *variation* of amplitude kI, say, so that the current in the circuit is now

$$(1 + k \sin nt)\, I$$

The force on the armature will be proportional to

$$I^2 + 2kI^2 \sin nt + 1/2\, k^2 I^2 + 1/2\, k^2 I^2 \cos 2nt$$

This is made up of a constant part, which does not sound the telephone, a part, $2kI^2 \sin nt$, which is a perfect copy of the voice, and a harmonic, $1/2\, k^2 I^2 \cos 2nt$. The distortion is relatively less the smaller the quantity k, which is called the fraction of complete modulation because if $k = 1$, the amplitude of the carrier current is periodically reduced to zero. It is clear that to completely modulate the carrier current the resistance of the microphone would need to vary from zero to infinity. This is done in telegraph sending, since the key is opened, but it can only be approximated with a microphone. There are two bad results of this incomplete modulation: The full power of the system is not used since it is only the variable part which transmits signals, and any irregularities or ripples in the carrier current have a relatively greater effect the smaller the modulation, since they are themselves modulations. There was therefore an imperative need of a resistance or current-varying device which would produce variations comparable with those produced by a telegraph key.

In our first circuit it is not necessary that the carrier current be constant; thus suppose it is represented by $I \cos rt$, in which $r/2\pi$ is a high (radio) frequency and hence inaudible. Upon modulation the current becomes

$$(1 + \sin nt)\, I \cos rt = I \cos rt + 1/2\, kI \sin (r + n)\, t - 1/2\, kI \sin (r - n)\, t$$

which defines a frequency band from $r - n$ to $r + n$. Thus if speech is to be transmitted (which requires all frequencies to about 3000) the high-frequency system must be capable of transmitting, not only the frequency $r/2\pi$ but a band extending 3000 cycles on each side of this frequency. This fact imposes a limit upon the sharpness of tuning allowable in carrier-wave telephony.

The above modulated current produces in the receiver (or an e.m.f. of this type produces in a rectifying detector) an effect roughly proportional to its square. Thus if there is impressed at the receiver another current, $A \cos r t$, in phase with $I \cos r t$, or equivalently, if the polarization of the receiver in the telephone case is made stronger, the audible frequency terms of the desired frequency will be reinforced while those of undesirable frequency will not play so prominent a part. Consequently, the received signal will be amplified with a minimum of distortion.

It is not intended to give here the theory of the modulation and detection of carrier waves, which should properly be treated in a separate paper, but this very brief sketch has shown the importance of complete modulation, the fact that radio telephony is concerned with the transmission of a high-frequency band instead of a single high frequency, and has indicated the possibility of new methods of transmission and reception.

INTRODUCTION OF THE AUDION

In 1906 Dr. Lee De Forest brought out a vacuum tube device which he called the " audion " and which has been described in the A. I. E. E. TRANSACTIONS. This was a very sensitive detector of electric oscillations and consisted of three electrodes in an exhausted envelope. One of the electrodes could be heated to incandescence with the result that electrons were emitted by it (the Edison effect). A battery connected between this electrode, as cathode, and another as anode resulted in a convection current of electrons from one to the other. Since negative electricity only was present, current could flow in but one direction. This is so far the action of the Fleming valve which also makes use of the Edison effect, but in the audion an epoch making advance was made in that the third electrode allows us to completely *control* the strength of the electron current *without consuming appreciable energy at that electrode or in its circuit.* In other words an inappreciable amount of power applied to the third electrode, or grid, will result in large changes in power in the anode circuit. Moreover, since the electrons have no appreciable inertia, the response in the anode circuit to stimuli in the grid circuit is practically instantaneous.

Now this kind of device is exactly what is needed as a repeater in telephony. It was therefore considered by the Bell

System and it was found that, provided the device could be so improved as to be able to handle the power required for wire telephony, the audion would make an ideal amplifier. In 1912 our audion development work was started with this in view, and the new device soon became a competitor of the so-called "mechanical" repeater, which it is displacing. This development of the telephone amplifier, fortunately, required a considerable amount of research in the field of high vacua and electron emission and also a rather extensive study of the electrical characteristics of thermoionic tubes.

This had two results immediately applicable to radio telephony. First, an application of the early studies of amplifying systems and circuits and particularly a study of "singing" or freely oscillating repeater systems by Dr. G. A. Campbell, resulted in a successful form of thermoionic oscillator, suitable for all frequencies, and second, through the work of Mr. E. H. Colpitts early in 1914, there was produced a thermionic modulation system giving approximately undistorted speech. Several related forms of modulating systems were soon after developed by van der Bijl and others.

Before describing the modulator it should be remarked that when one has a perfect amplifier and a perfect modulator, the problem of radio telephony is solved, at least theoretically, for all that is necessary is to modulate the output of an oscillator circuit and then, if necessary, amplify the modulated current. Or one may first generate oscillations of large power and modulate them by means of the amplified output of the telephone transmitter. It should also be remarked that a "perfect" modulator, *i.e.* one which may produce completely modulated undistorted carrier waves, is also a perfect detector of these waves.

Modulator. In order to understand the modulator, consider Fig. 1 in which is plotted a characteristic curve, C, of the audion. This curve shows the variation of anode, plate or output current with grid-filament or input voltage. Now let the tube be connected as shown in the circuit diagram in which two voltages are impressed simultaneously upon the grid. The first of these is due to a telephone transmitter, T, and is sufficient to vary the grid voltage from zero to the value $-E$. The second is of radio frequency and smaller than that due to the transmitter. The total voltage on the grid will then be shown, as a function of time, by the corrugated sine curve plotted vertically. The characteristic curve shows us that the resulting current in the output circuit will be represented by the variably corrugated curve extending to the right. The rapidly variable part of this curve represents a completely modulated high frequency current which may be led to an antenna or amplifier by the transformer at the right. It will be seen that the modulator acts essentially as an amplifier whose amplification is not constant but varies from zero (at the point $-E$) to a maximum at the extreme right. The object of introducing the battery e in the grid circuit is to insure that the grid will not become positive with respect to the filament, for as long as it is negative no electrons can flow to it and there will be practically no consumption of power in the grid circuit. It is, however, sometimes desirable to allow current in the grid circuit, in which case the battery may be adjusted.

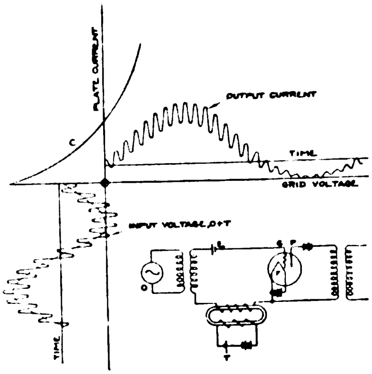


FIG. 1—MODULATOR SCHEMATIC

During the years 1912, 1913, 1914 a great deal of research work was carried on in connection with the development of the audion for telephony. There were many different problems involved in the manufacture of practical tubes which could handle the larger amounts of power necessary for amplifiers of telephone and radio currents. In the way of applications, laboratory apparatus was set up for amplifying telephone currents under long line conditions, a study of the detecting and rectifying properties of the tubes was made, circuits were designed for inter-connecting radio and wire telephone systems, oscillator circuits for both high and low frequencies were built, the audion was applied as a power-limiting device to protect circuits, and a number of other systems of modulation were devised.

FIRST FIELD TRIALS OF RADIO TELEPHONY

In 1914 it was decided that the apparatus and methods developed in the laboratory were sufficiently promising to warrant an attempt at transatlantic telephony.

In order that a practical demonstration of the method might be obtained an experimental station was constructed at Montauk, L. I., and a receiving station was constructed on the roof of the Dupont Building, in Wilmington, Del. A trial was made on April 4, 1915 in the presence of Professor Millikan and Colonel Reber, as well as Messrs. Carty, Gherardi, Jewett and others of the executives of the Engineering Departments of the American Telephone and Telegraph and the Western Electric Companies. The transmission was, of course, one way only. These gentlemen, therefore, witnessed the operation of the transmitting equipment at Montauk on one day and then on the following day visited the receiving station at Wilmington and listened to the incoming transmission. Wire connections between Montauk and Wilmington permitted the listeners at Wilmington to report immediately what words they had heard, or, as on the second day, it permitted the speaker at Montauk to report what he had said. The wire connection thus admitted of the verification of the experiment.

Following this demonstration the range was extended from Montauk to St. Simons Island off the coast of Georgia where a receiving antenna had been erected. For the purpose of this experiment the radio receiving circuit at St. Simons was connected to a telephone circuit leading to New York. Similarly, the radio transmitting equipment at Montauk was connected to a telephone line leading from New York. The speaker at New York talked over a wire circuit to Montauk, by wireless to St. Simons and then by wire to a listener in New York.

The method which was used in transmission was essentially that which was followed in later experiments when the Navy station at Arlington was used as a transmitting station. Prior to this time the inability of inventors to modulate large amounts of power in such a manner that the modulated current, when detected at the receiving station, could be obtained essentially free from distortion, had proven a serious limitation on the increase of range of transmission. It had been shown, however, that this limitation could be overcome by the use of the audion amplifier and modulator. The general method proposed, therefore, and the method finally developed was as follows. A small current of high-frequency was to be generated by means of a vacuum tube oscillator. This high-frequency current was to be modulated, essentially completely, by the voice current from the telephone transmitter. The resulting modulated current was to be amplified, or successively amplified, by distortionless amplifiers, of the vacuum tube type, until the energy which it represented was sufficient for transmission from an antenna over the desired distance.

For the production of a sustained high-frequency current a vacuum tube was used. With such a tube, provided its input and output circuits are coupled together and one of them contains a tuned circuit, the operation is one of successively amplifying its own output. This successive amplification will result after a moment in the development of a steady state of oscillation in which there is a definite maximum of output current. This maximum amplitude of the generated alternating current depends for its value upon the characteristics of the tube itself. An oscillation generator for producing alternating current is shown in Fig. 2. Power may be obtained from it by coupling loosely to the inductance of its circuit another inductance which in turn is connected to the point where this power is to be utilized.

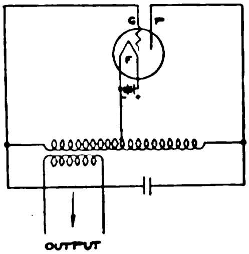


FIG. 2—OSCILLATION GENERATOR SCHEMATIC

As noted above, the study of the vacuum tube had also indicated that although it was possible to use the tube as a distortionless amplifier, it was also possible to adjust its voltages and the impedances to which it was connected so as to produce a distortion of the input current in a manner suitable for the purposes of radio telephony. Under such conditions the output of the tube contains a component which is proportional to the product of such voltages as may be simultaneously impressed upon its input or grid-filament circuit. If one of these inputs is obtained from the oscillation generator just described and the other from a telephone transmitter, it is then possible to obtain an output which varies harmonically with the frequency of the oscillation generator, and also varies harmonically in amplitude with the frequency of the voice current impressed by the transmitter.

A vacuum tube, properly designed for the impedances between which it was to be connected and properly adjusted so as to emphasize the modulator characteristics, was used as a modulator in the system of transmission which was formally demonstrated at Montauk. To its input was coupled inductively the tuned circuit of the oscillation generator and also telephone transmitter circuit containing a local battery.

In order to obtain a sufficient amount of energy for transmission over appreciable distances, it is necessary to amplify the energy output of the modulator before impressing it upon the antenna. In case considerable amplification is desired it may be obtained by impressing the voltage from the modulator upon an amplifying system formed by two amplifiers in tandem. It was also realized that amplifiers might be worked in parallel, that is, with their input circuits connected in parallel and with their output circuits connected in parallel, without introducing disturbing interactions, provided that certain precautions are taken. The method of amplification adopted for the Montauk tests and later used for the Arlington experiment was therefore a system of two stages of amplification. At Montauk the first stage was obtained by a single tube and the second stage by a number of tubes in parallel. In Fig. 3 is shown a view of the experimental apparatus used at Montauk. On the left in the foreground is a rack containing the amplifiers of the second stage. On the right, immediately above the battery racks, are four boxes containing the other radio apparatus. The upper right-hand box contains the oscillation generator. The box immediately below this holds the modulator and its associated apparatus; the upper box on the left contains the vacuum tube of the first stage of amplification; and the box below it has a tuned circuit and certain controlling resistances which enter into the transmission system. Another view of this apparatus is shown in Fig. 4. On the left of this is seen again the rack of amplifiers, but now in such a view as to show the vacuum tubes themselves. These tubes, which were similar to those later used in the Arlington demonstration, were especially designed for this purpose and are much larger than the vacuum tube amplifiers of telephone practise.

THE ARLINGTON-DARIEN EXPERIMENT

The tests from Montauk to Wilmington and to St. Simons Island were so successful that it appeared practicable to carry the method to its logical conclusion and to extend the range of radio telephony to much greater distances. For this purpose experiments were undertaken in conjunction with the Navy Department. For the initial steps in making such arrangements and for assistance throughout the experiments, we are indebted and distinctly grateful to Admiral R. S. Griffin, Engineer in Chief, U. S. Navy, Captain now Admiral W. H. G. Bullard, Superintendent of the Radio Service, and to Commander now Captain Hepburn and Lieutenant now Commander S. C. Hooper of the Bureau of Steam Engineering, U. S. N.

For the purpose of these experiments a small operating house was constructed beside the main operating building of the Navy Wireless Station at Arlington, Va. An antenna switch was provided so that the antenna might be connected to the Western Electric equipment in this experimental station. Captain Bullard also arranged for observers from the Western Electric Company to be present at the Navy stations at Darien, San Diego and Mare Island. The necessary apparatus was installed in the early summer of 1915 and preliminary experiments were started at once. On August 27th successful transmission was obtained to Darien on the Isthmus and was received by Mr. R. H. Wilson of the Western Electric Company and by Lieutenant R. S. Crenshaw of the Navy.

On this day Colonel Reber, Lieutenant Bryant of Captain Bullard's office and Mr. G. H. Clark, Radio Expert of the Bureau of Steam Engineering, had been asked to speak from Arlington in the hope that communication would be established with Darien. Immediately prior to the time these gentlemen spoke, two selections were played on a phonograph placed in front of the telephone transmitter. These were correctly recognized by Wilson and Lieutenant Crenshaw. Each of the visitors then spoke for a minute or two. The voices of the speakers were not familiar to the observers at Darien. Wilson, however, recognized the change in voice caused by a change in speaker and received correctly several phrases and some scattered words. These words were also verified by Lieutenant Crenshaw. A report of these results was sent immediately from Darien by Navy code to Arlington and was compared by the speakers with their records of their spoken words.

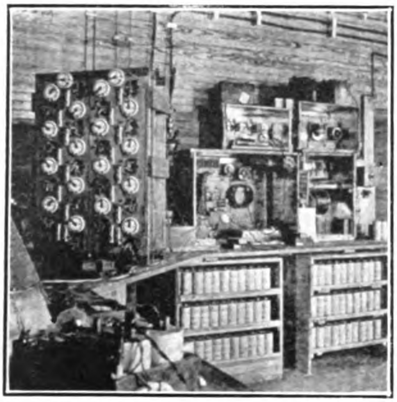


FIG. 3—MONTAUK EXPERIMENTAL APPARATUS

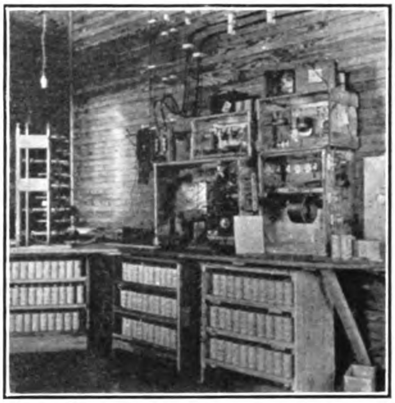
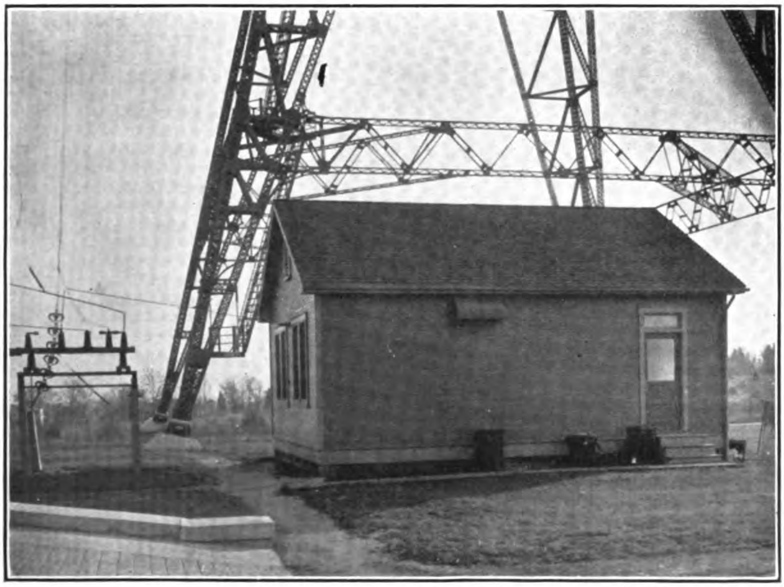


FIG. 4—MONTAUK EXPERIMENTAL APPARATUS



[CRAFT & COLPITTS]

FIG. 5—RADIO EXPERIMENTAL STATION, ARLINGTON, VA.

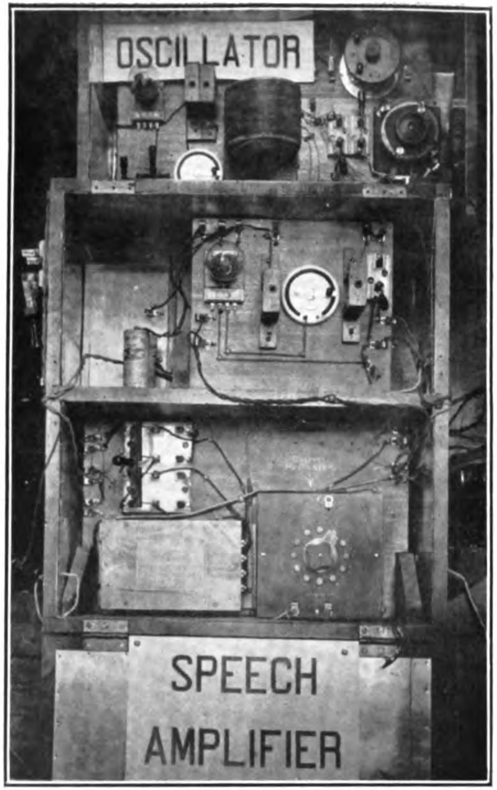


FIG. 6—SPEECH AMPLIFIER—RADIO EXPERIMENTAL STATION, ARLINGTON, VA.

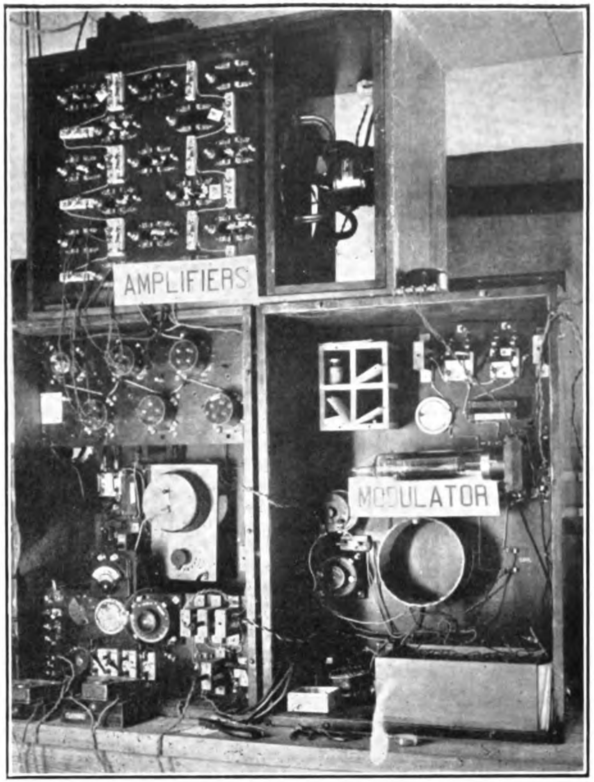


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FIG. 7—MODULATOR—RADIO EXPERIMENTAL STATION, ARLINGTON, VA.

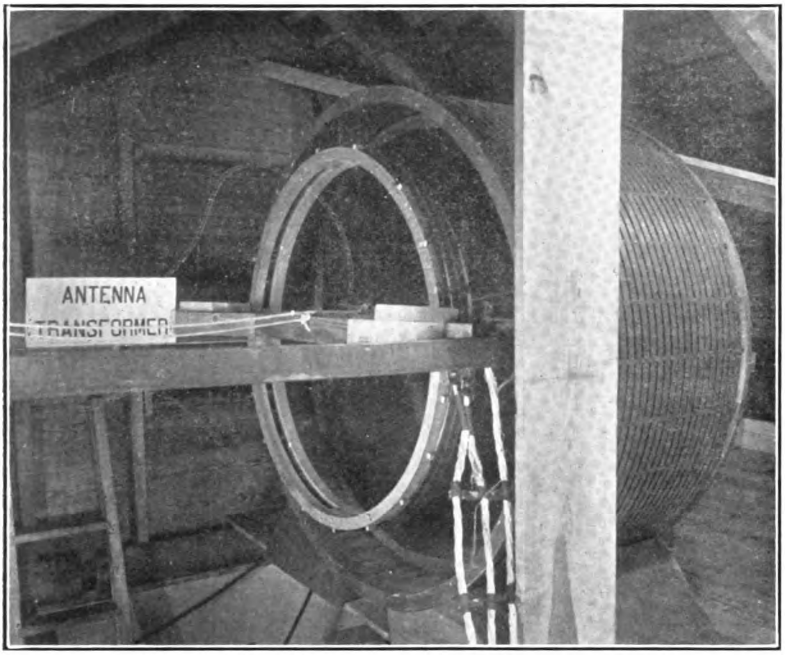

FIG. 8—ANTENNA TRANSFORMER—RADIO EXPERIMENTAL STATION, ARLINGTON, VA.

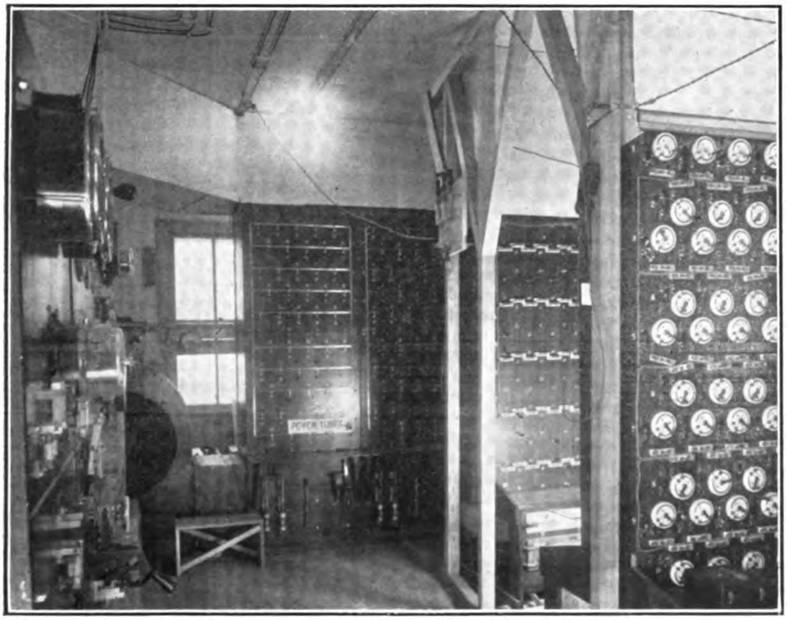

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FIG. 10—POWER TUBE RACK—RADIO EXPERIMENTAL STATION, ARLINGTON, VA.

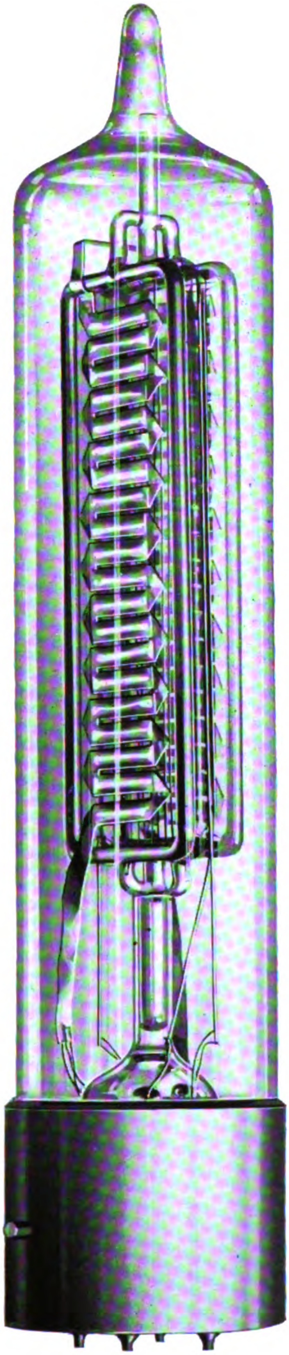

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FIG. 9—TYPE OF VACUUM TUBE USED IN LONG DISTANCE RADIO TELEPHONE EXPERIMENTS

The method of transmission was essentially that described above in connection with the Montauk experiment. The experimental station at Arlington is shown in Fig. 5. The transmitters used in these tests were of the ordinary commercial type, or of a type which was then in a stage of development and which it was thought might reproduce more exactly some of the higher harmonics of the voice. A phonograph was also used for the transmission of music. The output of the transmitter was amplified in a speech amplifier of the audion type, which is shown in Fig. 6. The high-frequency oscillator is shown in this figure above the amplifier where the tuning condensers and the coil for coupling to the inductance are plainly visible. The output of this speech amplifier and of the high-frequency oscillator were both impressed upon a modulator of the vacuum tube type, shown in Fig. 7. The voltage of this amplifier was not, however, high enough for the main amplyfying tubes, and it was stepped up by an intermediate group of amplifiers, of which six as a rule were used, which are shown at the left of the figure. The modulator output thus amplified was impressed upon a number of power tubes in parallel and then upon the antenna transformer shown in Fig. 8. The type of power tube is illustrated in Fig. 9. The amplifier tubes preceding the power tube and the modulator were also of the same form, but were of different constants, properly adapted to their purposes.

The current by which the filaments were heated was supplied by a local power company and brought in by underground cable to the operating station. Alternating current was used for heating the filament and any possibility of the superposition of a 60 or 120 cycle note, due to the frequency of this current, was eliminated by the use of a special scheme of connections. The transformers which were inserted in this circuit are shown at the left of the door in Fig. 5. Between the plate and the filament of the power tube a constant voltage of about 500 volts was impressed. It was obtained from one of the motor generators used by the Navy in operating the large Poulsen arc, with which they were then transmitting to Darien and other remote points. A large amount of energy, of course had to be dissipated in such an equipment because of the energy supplied to the filaments, and a blower was installed for this purpose as shown in Fig. 10 where the racks containing the power tubes are also visible. At the left of this figure is the switchboard for operating remotely the motor generator set in the main station of the Navy, for controlling the alternating current supplied to the filament, for operating the blower, and for metering the currents used for lighting the plant and for similar purposes.

The method of reception was varied from time to time as it was still in process of development. In some cases an amplifier for the high-frequency currents was introduced between the detector and the tuned circuit which was coupled to the antenna. In some cases a low-frequency amplifier was inserted between the detector and the receivers. In some of the later experiments a feed back circuit was used for the detector so that the detector tube itself acted as an oscillation generator as well as a detector. In that case the frequency of the oscillations was adjusted to be the same as those of the oscillation generator at the transmitting station.

THE NEW YORK-ARLINGTON-MARE ISLAND DEMONSTRATION

After obtaining successful communication with Darien, a distance of 2100 miles, attention was directed towards reaching the Pacific Coast stations of Mare Island and San Diego. As a test of the transmission efficiency, records were made at the W. E. Co's. laboratory in New York of the quality and intensity of the speech from Arlington, each time transmission was attempted. Records were also made occasionally at Darien, but no attempt was made to fit the time of transmission into the schedule of operation of that station. An order wire was set up between Arlington and the two Pacific Coast Stations, so that instructions as to the schedule of tests and reports as to its results might be conveniently interchanged.

Radio telephone transmission between Arlington and Mare Island was formally demonstrated on September 29th. On this date, Mr. J. J. Carty was inspecting the station at Mare Island. A demonstration for Mr. T. N. Vail was therefore arranged for this date.

The station at Mare Island consisted of a small house near enough to the operating house of the Navy so that the experimental apparatus might be connected to the antenna. The observers at the Mare Island station were Commander G. C. Sweet and Lieutenant Kenshit of the Navy, Mr. A. H. Babcock, Consulting Engineering Southern Pacific Railroad, Mr. J. J.

Carty and others. Messrs. Arnold and Hartley of the Western Electric Company were the experimenters.

Arrangements had been made whereby Mr. Vail's apartment in New York could be connected with the radio apparatus at Washington. A telephone line extended from the transmitter assigned to Mr. Vail's use to the radio telephone apparatus at Arlington. This telephone circuit was connected to the radio apparatus in place of the telephone transmitter which had formerly been used at Arlington. From Arlington transmission was through the ether to Mare Island. The telephone set which Mr. Carty used at Mare Island consisted of a transmitter connected to a telephone line leading, via the New York test board, to a receiver in Mr. Vail's apartment. The receiver of Mr. Carty's set at Mare Island was one of several which were supplied in parallel by the detector of the radio receiving set. Arrangements were thus made whereby Mr. Vail and Mr. Carty might carry on two-way conversation, but what Mr. Carty and the other observers heard at Mare Island was transmitted from Arlington by wireless.

At the New York toll test board a telephone line was bridged onto the circuit leading from Mr. Carty to Mr. Vail. This line extended to Arlington and contained one-way repeaters so that transmission could take place only from New York to Arlington. At the latter place it supplied a group of telephone receivers which were also connected through a one-way telephone repeater with the line which bore Mr. Vail's speech to the radio apparatus. In this way some dozen observers at Arlington could hear both sides of this unique conversation. The use of one-way repeaters prevented any interaction between the oppositely directed speeches.

At the Arlington station the conversation was listened to by Captain Bullard, Colonel Reber, Commander Hooper, Lt. R. B. Coffman, Lt. Bastedo, Commander Bryant, and members of the telephone system. Messrs. T. N. Vail, U. N. Bethel, J. I. Waterbury, Bancroft Gherardi, and H. P. Charlesworth all conversed with Mr. Carty through the ether.

THE ARLINGTON-HONOLULU EXPERIMENT

Having successfully transmitted over water to Darien, a distance of 2100 miles and over land to Mare Island, a distance of 2500 miles, attention was now directed towards reaching the remoter points of Honolulu and Paris. Schedules were therefore arranged for experiments with these stations. With Paris, however, the arrangements as to schedules were necessarily delayed because of the difficulties in cable transmission occasioned by the war.

With Honolulu, on the other hand, arrangements for a transmitting schedule had been made shortly before the demonstration of the New York-Arlington-Mare Island transmission. The first deliberate attempt to communicate with this station occurred on the night following the demonstration to Mare Island. Mr. Lloyd Espenschied of the American Telephone and Telegraph Company, who was the experimenter at this point, reported by cable the following morning, giving a record of the words which he had heard spoken, and also the name of the speaker, whose voice he had recognized.

THE ARLINGTON-PARIS EXPERIMENT

At Paris were Mr. Shreeve and Mr. Curtis of the Western Electric Company, in which connection it may be mentioned that they are again in France, the former as Lieutenant Colonel and the latter as Lieutenant in the Signal Corps. These experimenters had installed their apparatus in the Eiffel Tower station of the French Army. This courtesy had been accorded our representatives by Lieutenant Colonel Ferrié, Director of the Military system of Radio Telegraphy, to whom they had been introduced by Commander W. R. Sayles, Naval Attaché of the American Embassy. The magnificent spirit which France has shown throughout this bitter struggle is well illustrated by the ability of that nation to consider scientific developments, which apparently were not of immediate military value, and to assist in them despite the demands of the war. The amount of time during which our experimenters could use the antenna was, of course, very limited, and was small as compared to their necessities. The permission to use the antenna at a time when France was wholly engaged in this bitter struggle represents a contribution to science altogether disproportionate to the time which the antenna was available to our men. Unfortunately, however, much of the time when Mr. Shreeve and Mr. Curtis had access to the Eiffel Tower antenna there was interference from other high power stations on the Continent, such as Nauen, Eilvese, Clifden, Norddeich, Lyons and Vienna which were transmitting upon the same range of wave lengths as it was necessary for us to employ. Instructions from Paris to Arlington, to alter the wave length of the transmission, could be forwarded only by cable, and were, of course, subject to days of delay, so that a satisfactory and flexible working schedule was not to be hoped for. Further, it was possible to transmit in any one day only for a brief period. In spite of these difficulties, promising results in the way of clearly received speech at Paris were secured during short periods that it was possible to arrange for working, between October 12th and October 21st. On October 23d as a final demonstration a number of observers, including Commander Sayles and representatives of the French Army, listened to the telephone transmission from the Arlington station 3600 miles away. The wave length used was about 6000 meters and the antenna current at Arlington about 50 amperes.

On certain of the occasions when we had worked to Paris, Mr. Espenschied at Honolulu had been informed as to the schedule of tests. He had therefore listened in and copied the words spoken at Arlington. The conditions at his stations were, of course, much better that at Paris because of the absence of interference from high power stations in the neighborhood. His observations were upon transmission over a distance some 25 per cent greater than that from Arlington to Paris, and in part over land as well as sea water.

PRACTICAL DEVELOPMENTS

The impending danger of war put an end to the experiments as far as they were concerned with increase in range of transmission. The possibility of applying the principles which had been successfully developed in connection with these experiments in trans Atlantic and trans Pacific radio telephony to problems of immediate and patriotic value was of course evident. Subsequent developments and experimental tests were therefore directed solely with an aim toward their military value to the Army and the Navy. Some of these experimental developments which we made in this connection and the success with which they were accompanied may be of interest.

The first opportunity to demonstrate the use of the wireless telephone in war was presented early in 1916. Secretary Daniels desired a demonstration of what could be accomplished in the way of mobilizing the telegraph and telephone facilities of the country in case of war-time need. This was carried out by the American Telephone and Telegraph Company in May, 1916, and included as part of it wireless telephone communication with a battleship at sea.

The part played by the wireless telephone was to show the possibilities of quick communication by word of mouth between vessels at sea and Headquarters on land. A complete set was built and installed on the battleship New Hampshire. The transmitting to the battleship was done from our station at Arlington. The signals from the battleship were received at the Navy Yard at Norfolk with a set built for that purpose, and were automatically transferred to land telephone lines to Washington. The connections were brought directly to the mobilization switchboard at the Navy Department Annex. When it was desired to talk to the battleship, the regular telephone circuit from the Navy Department was connected up with the lines to Arlington and Norfolk, thus allowing communication by telephone to be held directly with the Captain of the vessel. It was found entirely practicable to hold two-way radio communication as effectively as over wire lines and to secure information or to give orders. Captain Chandler received his orders for manoeuvering in this experiment by wireless telephone from Secretary Daniels and Admiral Benson, and he reported to them each hour his position by the same means. The fact that the lines to the transmitting and receiving land stations came to Washington where these gentlemen were located did not mean that such an arrangement only was possible. This radio system was attached to the long distance telephone line and Capt. Chandler talked with Lt. Snyder of the Great Lakes Naval Station. It was then connected with the Transcontinental Telephone Line and he talked directly with Capt. F. M. Bennett, Commandant of the Mare Island Navy Yard. The ship during these conversations was 50 miles from Norfolk and outside the Capes.

The set installed on the New Hampshire differed from the set at Arlington only in size. The general circuit arrangement and modulation system was the same. The set was installed on the lower bridge deck and the telephone transmitter and receiver were installed on the bridge itself. This allowed the Captain, while on the bridge and directing the movement of the ship, to converse without leaving his post.

BATTLESHIP EQUIPMENT

The possibilities of the wireless telephone in Naval Maneuvering were quickly recognized by the Navy Department.

Commander Hooper of the Bureau of Steam Engineering asked us to cooperate in making the wireless telephone a useful piece of equipment in Naval service. It was decided to build two experimental sets, install them on battleships and give the operating staff an opportunity to investigate and criticize them operating point of view. The construction of two sets was begun in December 1915 and they were completed about the middle of January. A short description of these sets will not be out of place at this time. Each set consisted of complete transmitting and receiving sets with a motor-generator. The receiving set was built to be set on top of the transmitting set. A photograph of the two thus placed is shown in Fig. 11. An extension circuit was provided so as to allow placing the hand set either on the bridge or in the Admiral's or Captain's cabin so that it would not be necessary for them to go to the radio room to talk. A duplicate hand set was provided for the operator in the radio room as well as a head telephone for listening-in. The normal condition of the circuit was with the antenna connected to the receiving set. Any call thus coming in would be received. When a call was received and it was desired to talk instead of to listen, a button on the hand set was pressed which caused the relay operated antenna switch to disconnect the antenna from the receiving set and connect it to the transmitting set and at the same time start the transmitting set operating. This operation required only a fraction of a second. It was thus possible to transmit and receive suc-

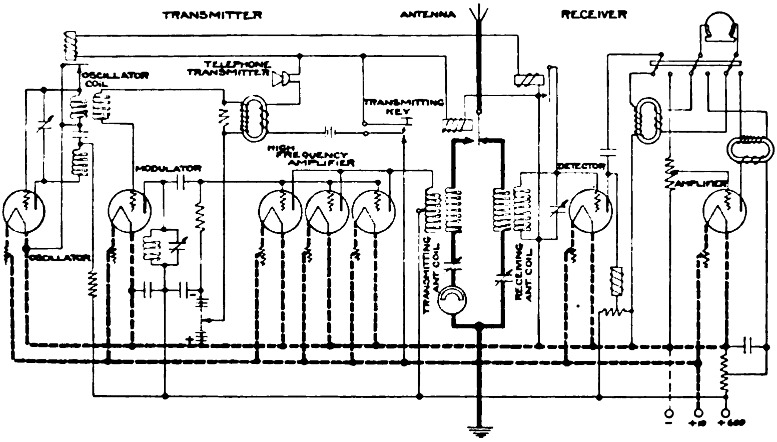


FIG. 12—CIRCUIT SCHEMATIC—BATTLESHIP SET

cessively on the same antenna by pressing the button whenever it was desired to talk. The wave length range of the set was 600 to 1200 meters. The circuit is shown in Fig. 12. This system was likewise similar to that at Arlington, but was, of course, quite small and produced only one and one-quarter amperes in the antenna. These sets were installed on the battleships Arkansas and Florida at Guantanamo, Cuba, the first part of February, 1916. It was found entirely practicable to hold a two-way conversation between vessels over 30 miles apart. There is no reason to think that was the limit of communication as some of these conversations were overheard in Jamaica, a distance of 175 miles. No attempt was made for range as that was not the object in building these sets.

MULTIPLEX WORKING

This experiment pointed out many things in the use of the wireless telephone which it was highly desirable to know. As the result, the Bureau of Steam Engineering approached us later in the same year and requested that a second step be made in the development of a satisfactory set. The fact that this set worked on the same wave lengths as their regular radio telegraph sets, caused considerable interference. It was desired in the telephone field to provide separate possibilities in communication for the Navy and not encroach upon the telegraph. It was, therefore, thought desirable to go to much shorter wave lengths and provide a set which would not interfere at all with the telegraphic operation of neighboring vessels and interfere very little with the telegraphic operations on the same vessel on which the telephone was being used. A few field experiments were made with short wave antennas on two ships in July 1916 to provide data necessary for building these sets and their design and construction was started in October. The new set differed from the old one in that it operated on three wave lengths, 150, 189, and 238 metres and also in that it was multiplex and allowed nine conversations to be carried on three wave lengths. The basis of the multiplex system which was originated by Mr. R. A. Heising is as follows:

Suppose a wave of 25,000 cycles is modulated according to a speech signal. This wave when received in the receiving set and rectified reproduces the desired speech. If, however, instead of radiating this 25,000-cycle wave directly, we modulate a 150-meter wave with it and radiate the 150-meter wave, on

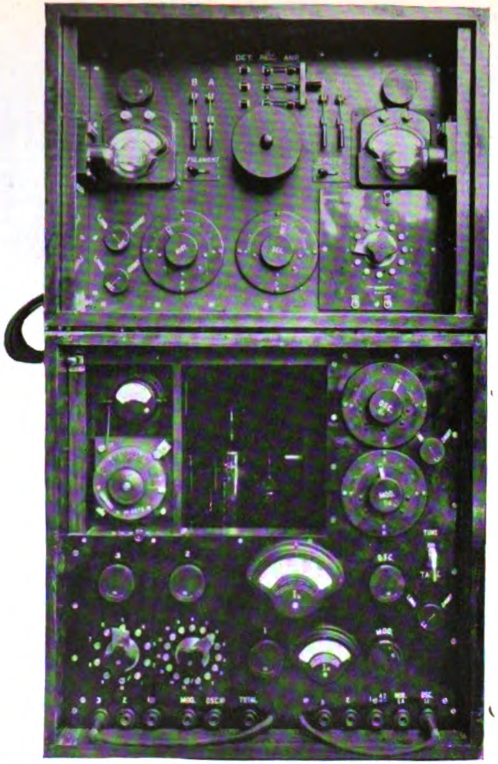
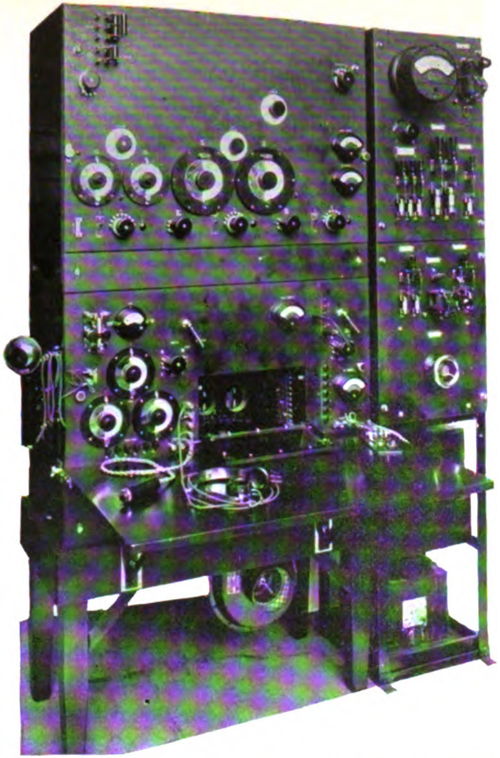


FIG. 11—BATTLESHIP RADIO TELEPHONE TRANSMITTING AND RECEIVING SET



[CRAFT & COLPITTS]

FIG. 15—MULTIPLEX TRANSMITTING AND RECEIVING SET

receiving and detecting at the receiving station the 150-meter wave there will be produced the wave of modulation, or the 25,000 cycle wave. This second wave, is, therefore, produced in the receiving station not by its direct radiation and reception, but is produced there by being carried by the shorter carrier wave. If it is then selected by tuned circuits and detected, the speech signal becomes audible. Therefore, with these sets provided, it was possible to have three ships transmit simultaneously on the same wave length, 150 meters for instance, one ship using an intermediate frequency of 25,000 cycles, the second an intermediate frequency of 35,000 cycles and the fourth, an intermediate frequency of 45,000 cycles. A receiving station tuned to 150 meters would receive all three double modulated waves. By using a second tuned circuit, one of the stations could pick out any one of these three conversations by tuning the second tuned circuit to 25,000, 35,000 or 45,000 cycles and detecting and would not be interfered with by the other two stations on the same wave length. A schematic diagram of the system is given in Fig. 13 and a circuit diagram of the receiving system is given in Fig. 14.

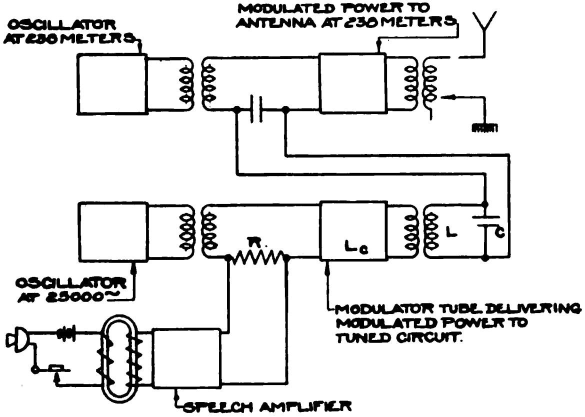

POWER TUBES DELIVERING MODULATED POWER TO ANTENNA AT 230 METERS
OSCILLATOR AT 230 METERS
R
Lc
L
C
OSCILLATOR AT 25000~
MODULATOR TUBE DELIVERING MODULATED POWER TO TUNED CIRCUIT.
SPEECH AMPLIFIER

FIG. 13—SCHEMATIC OF MULTIPLEX ARRANGEMENT

These sets were built upon the same plan as the previous ones in that transmitting and receiving sets were built to be placed one upon the other. An illustration is shown in Fig. 15. These sets were installed on the U. S. S. Pennsylvania, Wyoming and Seattle in January 1917, but scarcely had they been installed than diplomatic relations with Germany were severed and the assistance in the development of apparatus by the Operating Staff of the Navy was necessarily curtailed.

RADIO TELEPHONE APPARATUS FOR MILITARY USE

Beginning with the entry of this country into the war, the demands for radio apparatus for military purposes have resulted in the vary rapid commercial development of this type of equipment. While nothing fundamentally new has resulted from this work, there has been a very practical and valuable result in that the commercial development and manufacture of radio telephone apparatus in general has been put on a basis which otherwise could not have been reached for many years to come.

The first apparatus for war pruposes was built at the request of the Navy Department in March, 1917, and consisted of fifteen experimental sets which were proposed for use on submarine chasers. These sets were of the continuous wave type and were intended primarily for telegraph communication, but were also equipped with a telephone modulating attachment. The transmitting element employed four tubes of the type used in the trans-Atlantic experiments, and delivered approximately 1.5 amperes into the small antenna of the submarine chaser. In view of the fact that these sets were immediately replaced by an improved type which will be described later, the detailed construction of these sets need not be discussed, and they are mentioned merely to indicate the Navy Department's practical interest in this type of apparatus at a comparatively early date.

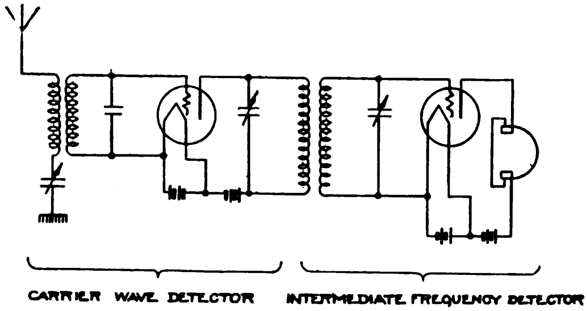


FIG. 14—SCHEMATIC OF MULTIPLEX RECEIVING CIRCUIT

AIRCRAFT TELEPHONY

The most prominent and probably most spectacular development of radio telephony during the war was in connection with its use on military aircraft. While radio telegraphy had been used before for fire control and scouting purposes, its field had not gone beyond that of one-way communication, and was confined practically to the use of simple spark gap types of telegraph apparatus.

Anticipating possible employment of radio telephony in this field, the Western Electric Company Engineering organization had done a considerable amount of experimental work in the way of applying the principles demonstrated in connection with earlier experiments in long distance radio telephony to short range work. This work had been carried on for some time under the direction of Mr. H. W. Nichols, and had resulted in the development in experimental form of satisfactory short range apparatus.

On May 22, 1917, Major General Squier, Chief Signal Officer of the Army, called a conference at Washington to consider the feasibility of intercommunication between airplanes while in flight by means of radio telephony. There were present at this conference besides General Squier, Colonel Rees of the Royal Flying Corps of Great Britain, Captain, now Colonel C. C. Culver of the Signal Corps and Major later Lieut. Colonel F. B. Jewett and Captain later Major E. B. Craft who had been assigned from the Western Electric Company Engineering Organization to engage in this work. At this time plans were in the making for the tremendous aircraft program which was later undertaken by the Army, and it was clear to all that a successful means of communication between battle planes when flying in squadrons would be of inestimable value and would greatly increase the efficiency with which these squadrons could be maneuvered. The early work had shown such promise that there was justification for assuring the Signal Corps that this means of communication could be worked out successfully and applied to aircraft of various types. As a result of this conference, orders were issued by the Signal Corps for the Western Electric Company to undertake the development of a wireless telephone system for the purpose. The experimental equipment available as a laboratory proposition at this time, served as a basis for the first experimental trials in the air. This transmitting set did not use the Colpitts system of modulation but the "constant current" system of R. A. Heising which was found to be more compact and easily operated. This system comprises a modulator and an oscillator tube with their plate circuits essentially in parallel for audio frequency currents. They are supplied from a generator through a choke coil whose function is to maintain a practically constant current to the two tubes no matter how the plate currents may vary individually. A circuit diagram is shown in Fig. 16 and the operation is as follows.

When the transmitter is not actuated there is a certain normal value of voltage impressed upon the grid of the modulator tube, this value being adjusted until the plate current of the modulator is about the same as that of the oscillator. Now the characteristic curve of Fig. 1 shows that as the grid becomes more negative the plate current decreases at constant plate voltage, and with positive grid voltage it increases. This may be described by saying that the resistance of the plate circuit may be varied by varying the grid voltage, and inspection of the curve shows that this variation may be from a very high value (point $-E$) to a small value for positive grid voltages. In the modulating system of Heising the transmitter voltage acts upon the grid of the modulator and causes the resistance of the plate circuit to vary through a wide range in accordance with the speech voltage. Since this circuit shunts the plate circuit of the oscillator tube (at audio but not at radio frequencies) the oscillator will be robbed of current or have additional plate current forced through it in accordance with

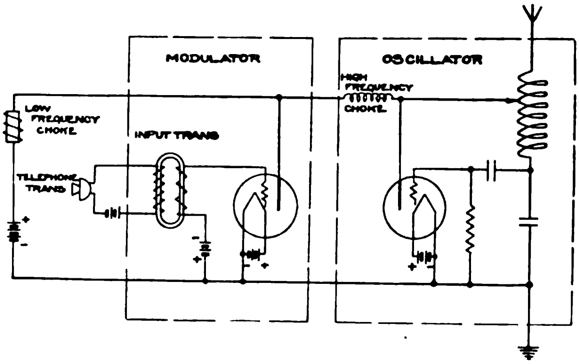


Fig. 16—Schematic of Heising Modulation System

the speech voltage. Its output will thus be varied and it has been found that speech is modulated in this way with very good quality. The efficiency of this system is high and greater than that of an "absorption" system in which power is variably diverted from an oscillating circuit and wasted in a modulating device. In the constant-current system the voltage and current in the oscillator rise periodically to nearly twice their values when the transmitter is not acting, which fact accounts for the increased efficiency.

EXPERIMENTAL WORK

This fundamental plan seemed to be the most feasible one to pursue and on June 5, 1917, another conference was held at Washington to agree upon the various technical features and make plans for carrying out field tests.

It was early realized that the principal difficulty in airplane telephony would be the noises due to the motor and the wind, so that attention was concentrated on the problem of providing against this difficulty both in the transmitting and receiving ends of the combination. Laboratory work was directed particularly toward producing a form of telephone transmitter or microphone which would be as insensitive as possible to these extraneous noises and at the same time be responsive to the voice frequencies. In order that this work might be carried on at high speed, a sound proof room was constructed and a device provided which reproduced very accurately the noises of the engine exhaust. By the first of July experiments looked sufficiently promising to warrant tests in the field. On July 2nd a complete radio telephone transmitting equipment was taken into the air and speech of good volume and quality was received on the ground, with the transmitting plane two miles away. The development of a suitable receiving head set was carried on simultaneously and it was found possible to devise a leather helmet with the receiving elements so disposed and screened from external noises that the weak radio signals could be readily observed. On July 4th experimental receiving equipment was taken into the air and Mr. L. M. Clement of the Western Electric Company successfully received speech from the ground at a distance of several miles.

As stated before, the apparatus used in these tests was of an experimental form built in the laboratory. The transmitting set had an output of 0.7 amperes at a wave length range of

200 to 400 meters, the antenna being a trailing wire about 100 meters along.

DEVELOPMENT OF APPARATUS

With the information resulting from these tests, the development of a practical airplane set began at once. During the previous month, comparative tests had been made on a number of proposed modulating systems, with the result that the constant-current system previously described seemed best for the purpose. The problem now was to produce sets of minimum size and weight, physical structures which would withstand the extreme vibrations and jars encountered in flying, especially in landing, the most convenient disposition of control elements, suitable sources of power for both high and low voltage, and a form of antenna which would not interfere with the evolutions of a plane in squadron formation.

It was realized that the solution of the last mentioned problem would consume more time than was at our disposal, and while work was immediately started in the field on antenna measurements and study, the design of the sets proceeded on the basis of using a trailing wire antenna.

The working out of a practical helmet design proved to be more difficult than the success of the earlier experiments indicated. It was found that the degree of interference experienced changed very rapidly with slight imperfections in fit. The problem was also complicated by the necessity of providing means for using oxygen at high altitudes, and of providing for the comfort of the wearer over a period of several hours. It was found that a very slight amount of pressure on certain portions of the ear caused excessive pains and headaches after a very short period, and the final design was a compromise between comfort and efficiency as to sound insulation. Fig. 17 illustrates the form of helmet that was eventually developed and adopted.

The problem of power supply was an interesting one. It was required that the weight should be reduced to a minimum, which precluded the possibility of employing storage batteries. There are obvious objections, also, to attaching any form of generating device to the propelling engine. Consideration of all the factors led to the adoption of a wind-driven generator for the purpose. This generator of about 100 watts direct current output was required to produce a potential of 300 volts for the plate circuits of the vacuum tubes, and a potential of 25 volts for the filament circuits. It is necessary, to insure most efficient operation, that the filament current be kept constant, and the fact that the specifications called for operation with airplane speeds varying from 40 to 160 miles per hour made the problem of voltage regulation loom large. Ordinary forms of electro-mechanical regulating devices did not prove to be successful and while it was probable that something of this type would eventually have been developed, the problem was solved by a very ingenious arrangement proposed by Mr. H. M. Stoller, in which the vacuum tube is the essential element. Fig. 18 shows, schematically, the generator and regulator circuit. The voltage of the generator is held approximately constant by means of a vacuum tube regulator, which controls the field flux. Two field windings are provided, the main field, which is in series with the filament of the regulator tube, and a differential field which is in series with the plate circuit. At minimum speed the differential field is inactive and the generator behaves like an ordinary shunt machine, except that the main field has a small resistance in series due to the regulator tube filament. This filament is so designed

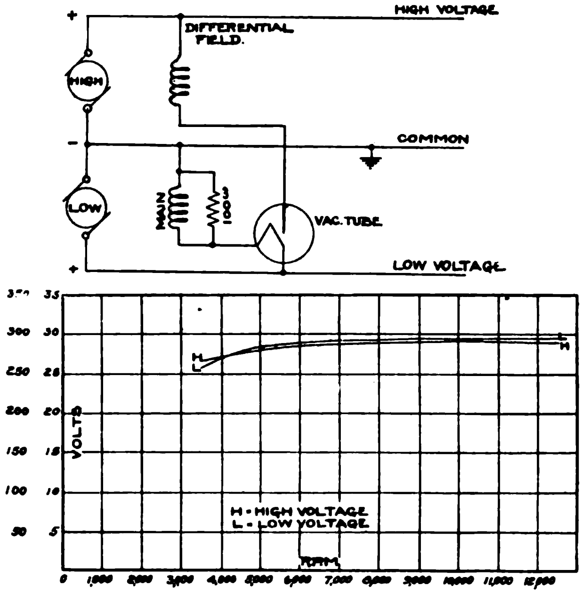


FIG. 18—VOLTAGE REGULATION OF WIND-DRIVEN GENERATOR

that the main field current heats it to a temperature which gives a small electron current. This current flows through the differential field and reduces the resultant flux. At minimum speed, the differential current is small, but as the speed increases, the main field current tends to rise (as in any shunt generator) and this increases the temperature of the regulator tube filament. The electron current is, therefore, considerably increased, which current, flowing through the differential field, reduces the generator flux and thus restricts the rise in voltage. Due to the fact that the electron current of the regulator tube increases very rapidly with increase in filament current, the voltage is held practically constant between 4000 and 12,000 rev. per min. The 1.5-ohm resistance units are provided so that the regulator may be set to give different voltages by cutting them in or out of the main field. The 100 ohms shunt resistance is used to prevent hunting.

Upon the completion of the next set of models, field tests were resumed and on August 20th the first two-way telephone conversation between two planes in the air was successfully accomplished.. After this first trial, Major Bartholf and Lt. Stevens of the Signal Corps held two-way conversation between planes with very satisfactory results.

In Figs. 19 to 24 are shown the apparatus that was employed in the August tests at Langley Field. At this time two general schemes of control were considered,—manual means for transferring from the transmitting to the receiving position, and automatic means for accomplishing the same result through the operation of a remote control relay. It was concluded, because of its simple construction, to employ the manual means of control, the idea being to locate the set in the observers position in the plane.

On August 22nd an informal demonstration of talk from airplane to ground was given for Secretary of War Baker, General Scott, and Colonel Baker. These experiments conclusively demonstrated the practicability of the system and apparatus, and we felt justified in proceeding with its commercial development.

Commercial Development

VACUUM TUBES

While the vacuum tubes that had been developed in the 1915 and 1916 experiments were satisfactory in operation under normal conditions, it was found that the mechanical vibration

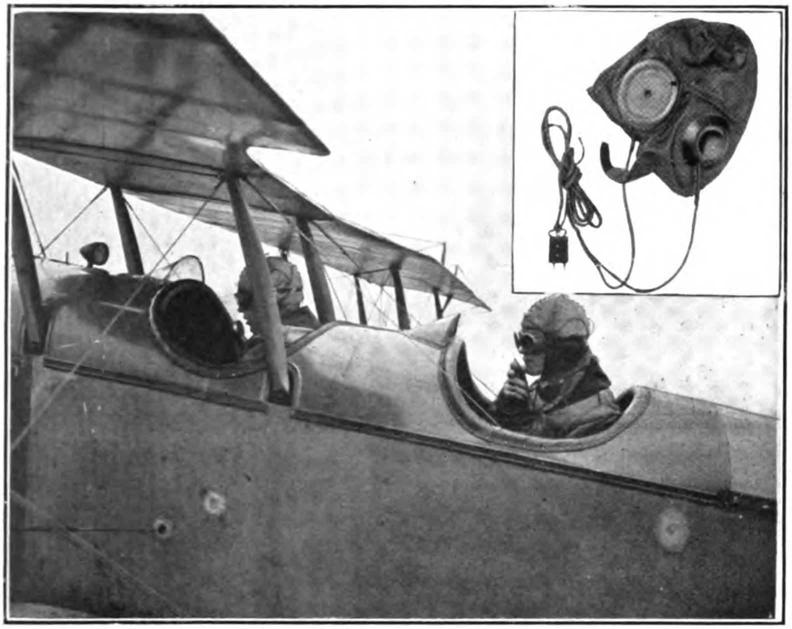


FIG. 17—TELEPHONE RECEIVING HELMET FOR AIRPLANE RADIO

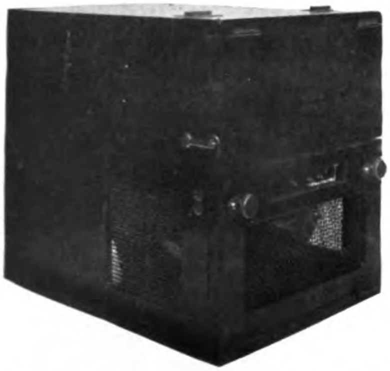


FIG. 19—EARLY FORM OF AIRPLANE TRANSMITTING SET

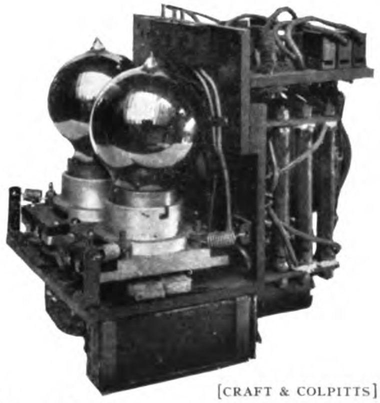


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FIG. 20—TRANSMITTING SET—OPEN VIEW

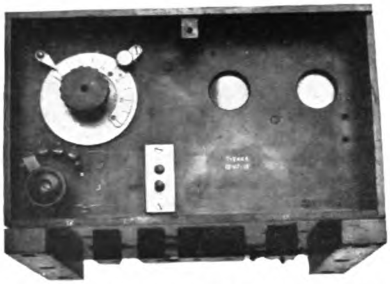

FIG. 21—EARLY FORM OF AIRPLANE RECEIVING SET

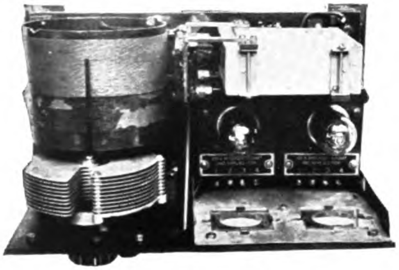

FIG. 22—AIRPLANE RECEIVING SET—OPEN VIEW

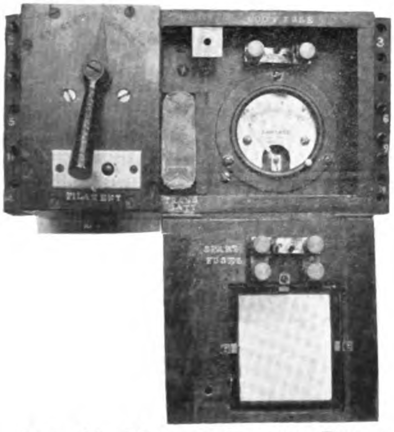

FIG. 23—MANUAL CONTROL BOX—AIRPLANE RADIO

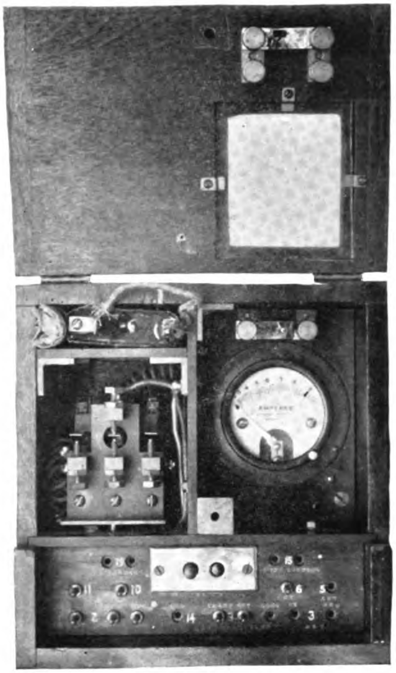

FIG. 24—REMOTE CONTROL BOX—AIRPLANE RADIO

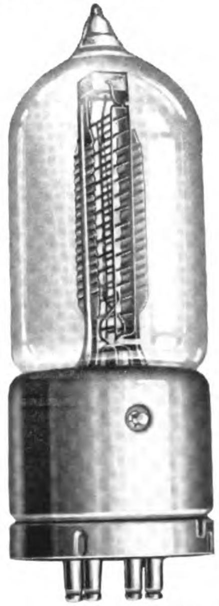

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FIG. 25—WESTERN ELECTRIC RECEIVING TYPE VACUUM TUBE—ARMY AND NAVY STANDARD

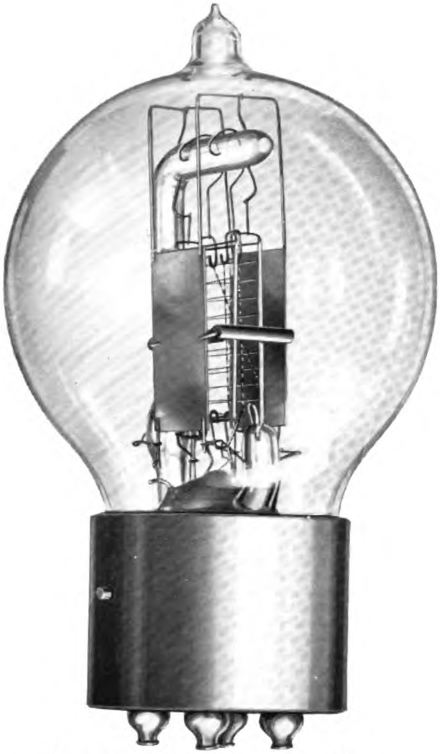

FIG. 26—EARLY FORM OF WESTERN ELECTRIC TRANSMITTING TYPE VACUUM TUBE

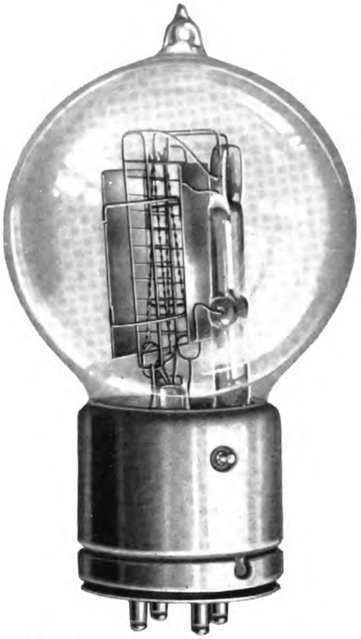

FIG. 27—WESTERN ELECTRIC TRANSMITTING TYPE VACUUM TUBE—ARMY AND NAVY STANDARD

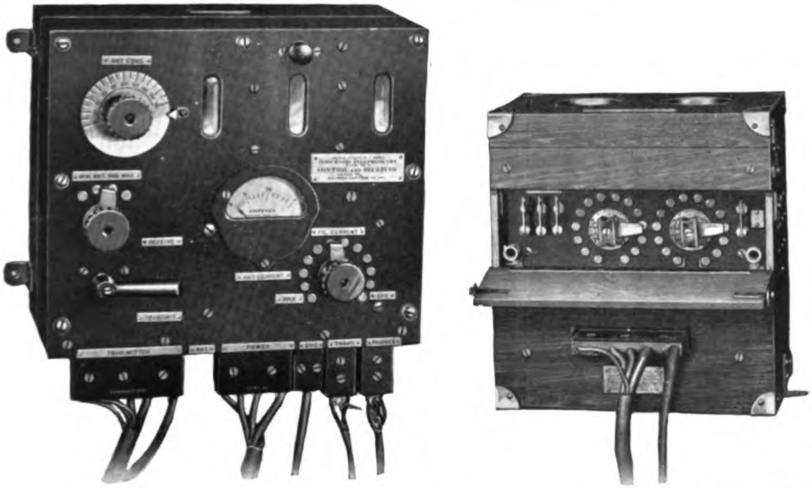

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FIG. 30—WESTERN ELECTRIC AIRPLANE TRANSMITTING AND RECEIVING SET—FIRST STANDARD TYPE ADOPTED BY THE SIGNAL CORPS

encountered in the air was such as to necessitate special structures to withstand them. New forms of vacuum tubes, which successfully met these requirements were developed. Fig. 25 shows the receiving tube in which the elements are supported in a metallic framework, thus eliminating a great deal of breakage which occurred in the earlier structures. Fig. 26 shows the first form of power tube which was developed, later followed by the type shown in Fig. 27.

The vacuum tubes used in all this work were of the so-called "Wehnelt Cathode" type; that is, the electron-emitting cathode consisting of a metal filament—usually platinum—coated with a mixture of oxides which, when heated to a moderate temperature, gives off electrons in great numbers. When properly constructed and treated, such a type has several great advantages:

1. For a given electron emission, the temperature is not so near the point of destruction due to evaporation, etc., as in the case of a pure metal—for instance, tungsten. The result is longer life in operation.
2. For a given change in filament current at working ranges the change in electron emission is smaller in the case of the Wehnelt cathode, permitting of closer regulation in power output.
3. Evaporation of the filament does not go on so rapidly, consequently its electrical behavior is more uniform throughout its life.
4. The electron emission for a given amount of energy supplied to the cathode is larger, resulting in more economical operation of the sets.

It was found that for transmitting and receiving purposes, two types of tube were sufficient. The tube for receiving purposes was designated as VT1 by the Signal Corps and as the CW933 by the Navy. A transmitting tube capable of delivering a moderate amount of power—say from 3 to 5 watts high-frequency output—was known as the VT2 by the Signal Corps and as the CW931 by the Navy. Vacuum tubes are defined, as far as electrical characteristics in normal operation are concerned, by plate and filament voltages, plate current with normal plate voltage and zero grid voltage, normal filament current, filament life at this current, and by what is known as the amplification constant, which is approximately the ratio, μ, of that change in plate voltage which produces a given change in plate current to the change in grid voltage to produce the same change in plate current.

Some of these relations are conveniently shown in characteristic curves. The plate current-grid voltage characteristics of the *VT*1 and *VT*2 tubes are shown in Figs. 28 and 29. On these illustrations are given also the other data mentioned above.

As indicating some of the problems involved in the commercial production of this entirely new type of equipment, it is interesting to note that prior to August, 1917, the total output of commercial vacuum tubes of this general type was approximately 200 per week, their use being practically confined to long distance wire telephony and to radio detection purposes. On November 11th, 1918, deliveries were being made at the rate of 25,000 per week. This involved the organization of equipment and personnel to do a class of work for which there was practically no experienced talent available and the situation in many features was analogous to that in connection with airplane production.

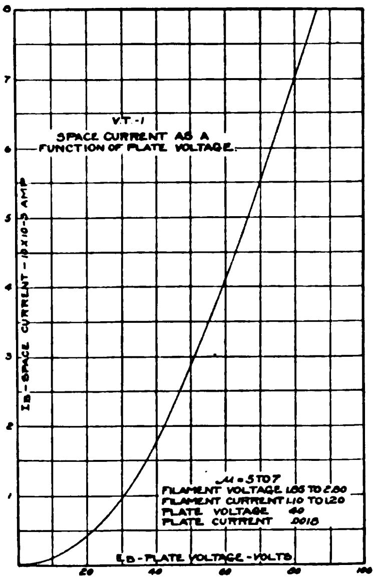

Fig. 28—Characteristics of Receiving Tube *V T*-1

Apparatus

Tests of the first standardized sets for Signal Corps use were made at Langley Field on October 6th. These sets operated very successfully and official demonstrations of two-way communication were made. This set was made up of a combined control panel and receiver with two stages of amplification and a separate transmitting set, the electrical connections being made by flexible cords. These units are illustrated in Fig. 30. By means of the multi-contact manual switch located on the control panel, the operator can receive or transmit as desired. The receiver consists of a single tuned circuit of the very simplest type and the amplifier is made adjustable for the convenience of the observer.

While the original requirement was that communication should be maintained at a distance of 2000 yards, all of the tests indicated that successful communication could be obtained at much greater distances. On October 16th an official distance test was made, and communication between planes was maintained at a distance of 23 miles, and from plane to ground, 45 miles. The conditions under which these tests were made were extremely favorable, and are noted merely to show the possibilities of this particular equipment. The figure that was finally established as being representative of what would be required in service, was three miles.

A number of sets were immediately constructed, and complete equipment sent overseas with Signal Corps Officers, where they were submitted for the criticism of our military forces.

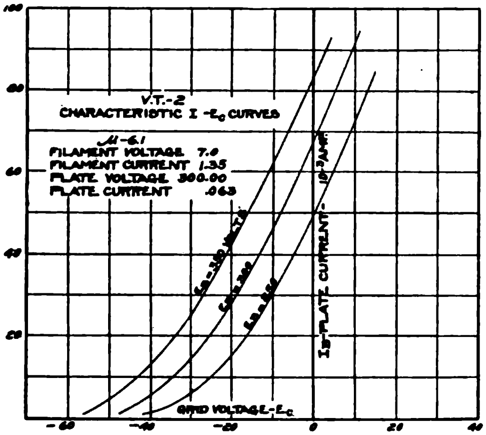

FIG. 29—CHARACTERISTICS OF TRANSMITTING TUBE *V T*-2

Several more demonstrations of this apparatus were made, culminating in the official trials at Dayton, Ohio, on December 2nd, 1917. There were present members of the Aircraft Production Board and the joint Army and Navy Technical Board, and various Signal Corps Officers. The demonstration consisted of a three-cornered conversation between two planes in the air and a ground station. At the ground station a loud speaking receiver was connected to the radio set in such a way that the entire party of about thirty could overhear the conversation between the fliers and also the speech between the planes and the ground. Under orders transmitted from the ground station, the fliers performed various evolutions in the air, and the observers could see these orders carried out and hear the acknowledgments. In these tests the pilot and observer in each plane were also connected, so that there were five people in constant communication. The maximum distance of the planes from the ground station was about eight miles, at which distance they were invisible. These tests so conclusively demonstrated the possibilities of the successful use of this apparatus, that quantity orders were immediately placed by the Signal Corps.

The time elements were very short and the problem of adapting the designs to commercial quantity manufacture were many and intricate. This probably is the first instance on record in which the production of radio apparatus, either telephone or telegraph, has been put on a manufacturing basis, in quantities comparable with that obtaining in ordinary lines of electrical manufacture.

The apparatus represents not what would be designed and built under normal conditions with time available for proper study of all the technical features involved, but the best compromise, bringing in such factors as the use of standard parts, available manufacturing facilities and finally the imperative need of haste.

Information from abroad was at times conflicting and inadequate, so that the Signal Corps Officers in Washington were often required to render decisions on important points under exceedingly difficult circumstances. We are greatly indebted to Lt. Col. N. H. Slaughter and other officers of the Signal Corps for their effective cooperation in the solution of difficult problems arising from all these causes.

The final standardized form of two-way airplane set is known by the Signal Corps as the SCR-68 set. Fig. 31 shows the complete equipment for a two-place airplane. The elements are so arranged that they can be mounted in the space available in various parts of the machine. The main set, however, necessitates being accessible to the operator.

The switch box, shown in the center, is to provide for communication between pilot and observer by means of the same helmets and microphones as are used for radio communication. This is one of the interesting by-products resulting from the radio development. Heretofore the only practicable means of communication between pilot and observer was by means

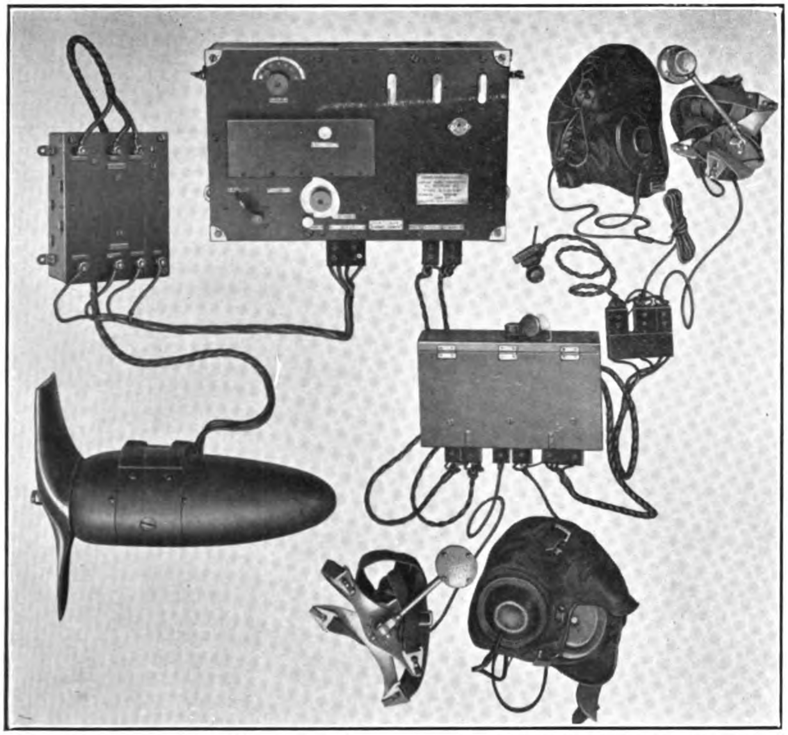

FIG. 31—COMPLETE WESTERN ELECTRIC RADIO TELEPHONE EQUIPMENT FOR TWO-PLACE AIRPLANE—SIGNAL CORPS STANDARD SCR-68

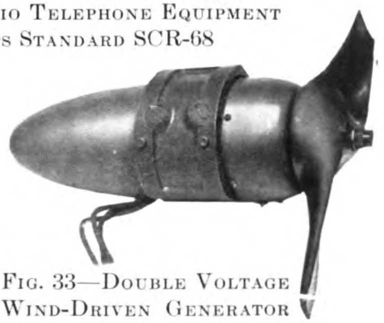

FIG. 33—DOUBLE VOLTAGE WIND-DRIVEN GENERATOR

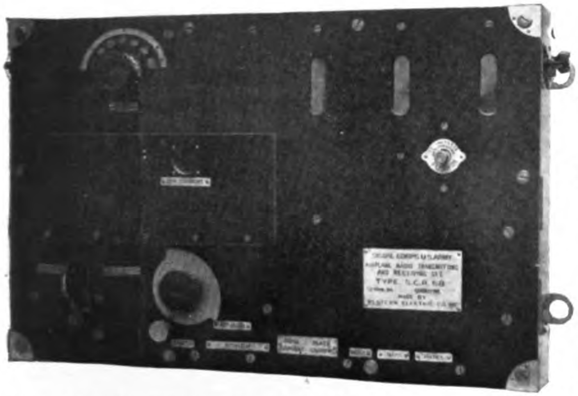

FIG. 32—TRANSMITTING AND RECEIVING SET BOX —SIGNAL CORPS SCR-68

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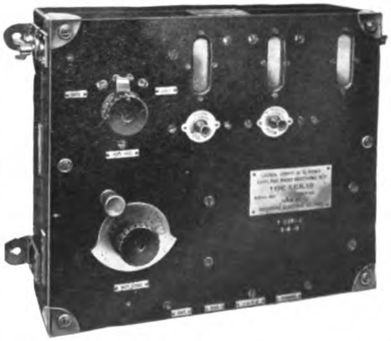

FIG. 37—WESTERN ELECTRIC RADIO TELEPHONE RECEIVING SET—SIGNAL CORPS S C R-59

PLATE XXIII.
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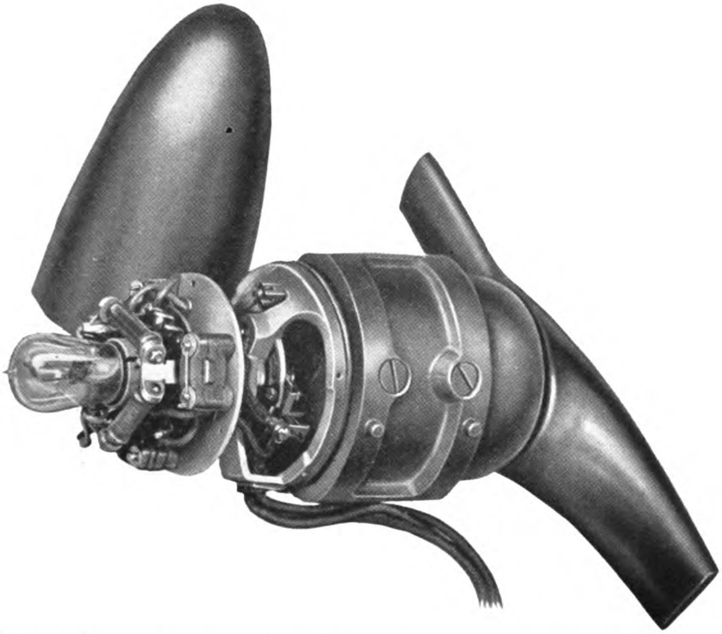
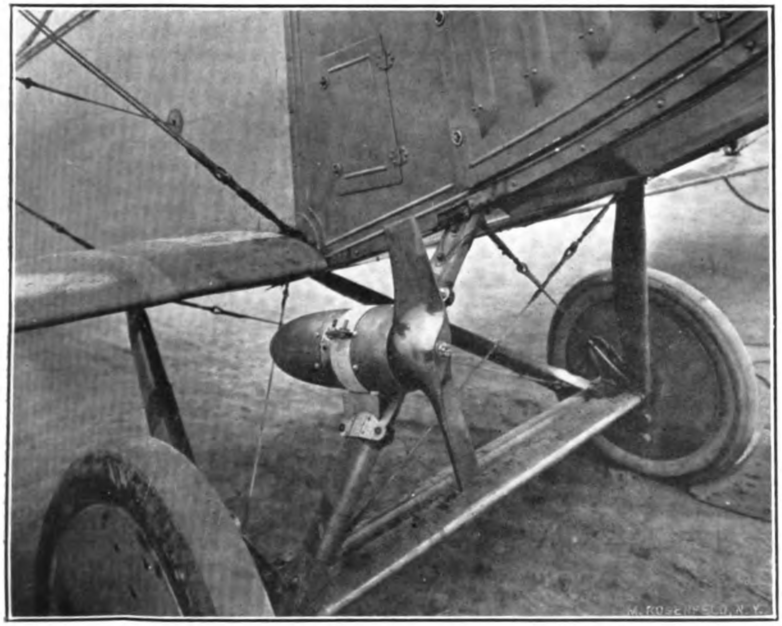


Fig. 34—Wind Driven Generator Showing Voltage Regulating Tube



[CRAFT & COLPITTS]

Fig. 35—Method of Mounting Wind Driven Generator

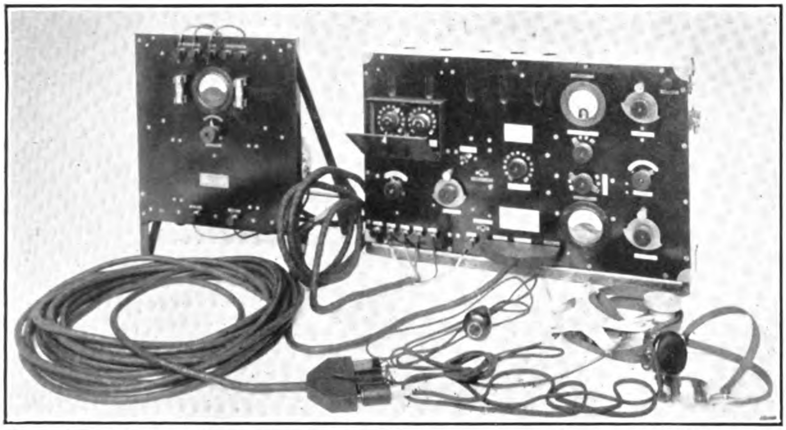


FIG. 38—RADIO TELEPHONE TRANSMITTING AND RECEIVING SET FOR GROUND USE—SIGNAL CORPS S C R-67

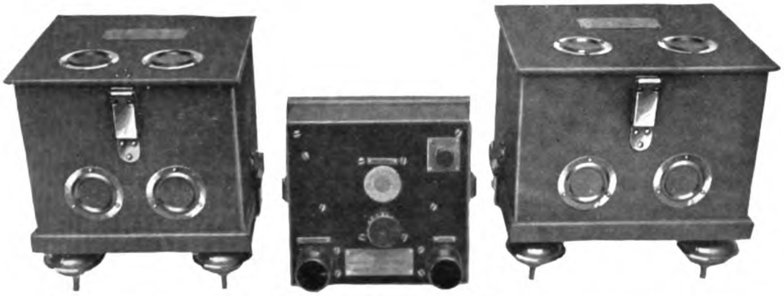
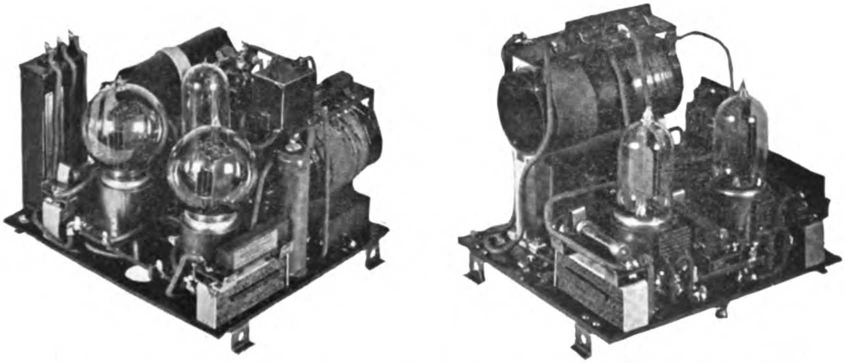


FIG. 39—SHORT WAVE TYPE AIRPLANE RADIO TELEPHONE SET



[CRAFTS & COLPITTS]

FIG. 40—INTERIOR CONSTRUCTION OF SHORT WAVE TRANSMITTING AND RECEIVING UNITS

of manual signals. With the telephone equipment, satisfactory intercommunication could be provided at all times. This has been found very useful in connection with the training of fliers as well as in military operations.

The transmitting and receiving set proper is shown in Fig. 32. This set is approximately 17 by 10 by 7 in. in dimensions, and weighs 21 lb.

The wind-driven generator is shown in Fig. 33, and in Fig. 34 the tail cover has been removed showing the vacuum tube regulating device.

The generator is usually mounted in the slip stream of the propeller on one of the struts of the landing gear, as shown in Fig. 35.

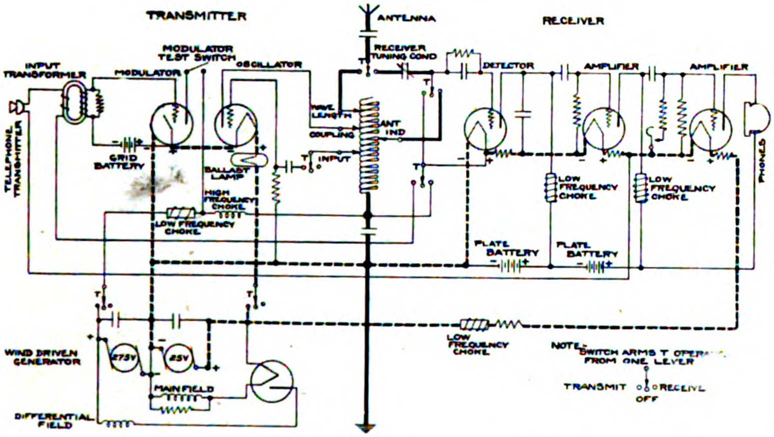


Fig. 36—Schematic Circuit Diagram—Radio Telephone Transmitting and Receiving Set—Signal Corps SCR-68

The weight of the complete equipment including generator and two operators sets is approximately 58 pounds.

Fig. 36 shows, in simplified form, the electrical circuits.

When receiving only is required, the transmitting portion is omitted, and power is supplied to the filaments by a small storage battery. The receiving set is shown in Fig. 37.

Modifications of the SCR-68 sets adapted to different classes of service were developed and manufactured, one of the principal adaptations being a combination transmitting and receiving set for use on the ground. This is illustrated in Fig. 38. This set was employed principally for training purposes. With this means of communication at hand, the performance of the student could be observed in the air and his faults could be corrected by the instructor on the ground, thus greatly accelerating this training work. Energy for this set was provided by storage batteries, a dynamotor being operated by the storage battery to supply the plate potential.

Up to the time of the signing of the Armistice, many thousands of these sets had been manufactured and delivered.

SHORT WAVE TYPE

Since the first experiments the trailing wire antenna had been employed and wave lengths of from 200 to 500 meters were used. It was realized that a long trailing wire antenna was not well adapted for use on military airplanes for tactical reasons, and it would be very desirable to limit the physical dimensions of the radiating system. This, of course, implies a corresponding reduction in the length of wave radiated if an efficient system is to be used, and steps were taken to design such a set. There is no difficulty in securing extremely short waves with the vacuum tube oscillator but there is some difficulty in designing a very compact set, with wave length adjustable over a considerable range and containing amplifiers and modulators, and at the same time avoiding excessive losses. In October, 1917, some laboratory sets were made for wave lengths of the order of 70 to 150 meters, and early in 1918 the Signal Corps requested the development of a short wave set. This was built in April and was electrically essentially the same as the longer wave sets except for minor changes due to the use of higher frequencies of the order of 4,000,000 cycles.

Trials of this system were made at Camp Alfred Vail at wave lengths of 60 meters and above. The antenna first used was a very short structure on the top of the plane with two wires extending to the tail. This antenna had a natural wave length of 32 meters and a resistance of only one ohm. To increase the radiating qualities the rear portion of the antenna was raised and the resistance thereby brought up to nearly 3 ohms at 75 meters. This structure did not materially increase the head resistance of the plane and did not interfere with its operation. As described later, this form of antenna was soon replaced by another.

The use of short wave lengths brings froward prominently the problem of location of component parts of the set in the plane, for a few unnecessary feet of connecting wire carrying these high frequency currents may cause the failure of the set. For this reason considerable thought was given to the question of location of transmitter and control box. Fig. 39 shows the final form of these short wave sets and it will be observed that the multiple unit plan of assembly has been carried further than heretofore, and this was due to the fact that difficulty was encountered in mounting the SCR-68 type set in the single place combat planes.

Fig. 40 shows the interior construction of the short wave transmitting and receiving units.

RADIATING SYSTEMS

The whole subject of proper radiating systems for use on planes was one to which more time should have been applied than was available at the time of development and manufacture of the first apparatus. A considerable amount of work, however, was carried on and valuable data obtained. This work was started in the summer of 1917 at Langley Field, and was later transferred to Camp Alfred Vail, N. J. The work was in charge of Mr. A. A. Oswald of the Western Electric Co. under the direction of the Signal Corps, and resulted in the accumulation of a considerable amount of useful data on many types of antenna. There are three important conditions to be met in designing an antenna for use on airplanes.

1. It must be an efficient radiator.
2. It must not be directive.
3. It must not interfere with complicated evolutions of the plane.

The third condition practically prohibits the use of a long trailing wire with a weight, because of the danger of fouling the propellor. This type of antenna is also quite directive.

The details of this antenna investigation should properly be covered in a separate paper. It may be well to state, however, that the best system, all things considered, was found to consist of two short unweighted wires, one from each wing tip. The two wires were joined in parallel above the fuselage, and worked against the conducting portions of the plane as a counterpoise. It was found that the use of one such wire as antenna and the other as counterpoise was not good.

In Fig. 41 the distribution of intensity of radiation is shown with the single long trailing wire and the two wire type of antenna.

IGNITION INTERFERENCE

Another problem arose when sets began to be installed. This was that of noise in the receiving sets due to the engine ignition, and was very serious in some cases. Its solution was complicated by the fact that it was not allowable to alter the plane equipment in any way, for instance by changing the position of one magneto to secure greater shielding, but it was found that by covering the ignition wires with a flexible conducting tube grounded at intervals this trouble could be practically eliminated.

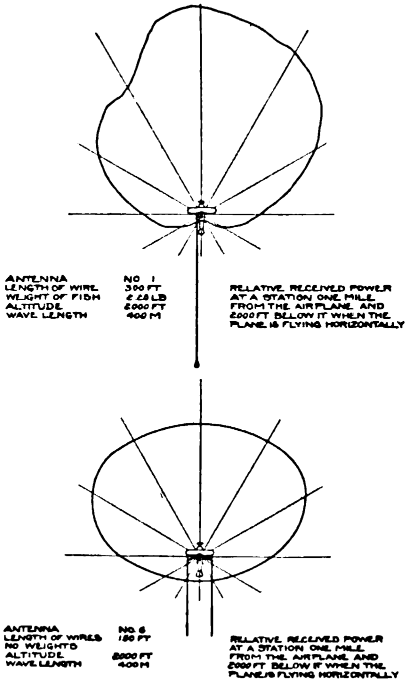


FIG. 41—DIRECTIONAL CHARACTERISTICS OF AIRPLANE ANTENNA

It was found that in some cases the ignition spark started in the ignition system high-frequency oscillations which were of proper frequency to affect the receiver. This happened on the submarine chasers, which are driven by gasoline engines, and the trouble was remedied by inserting small iron core choke coils in the ignition leads to change the frequency of the oscillations. It is obvious that the "radio signals" sent out by the ignition spark are many millions of times more intense than those to be received and it is remarkable that they do not

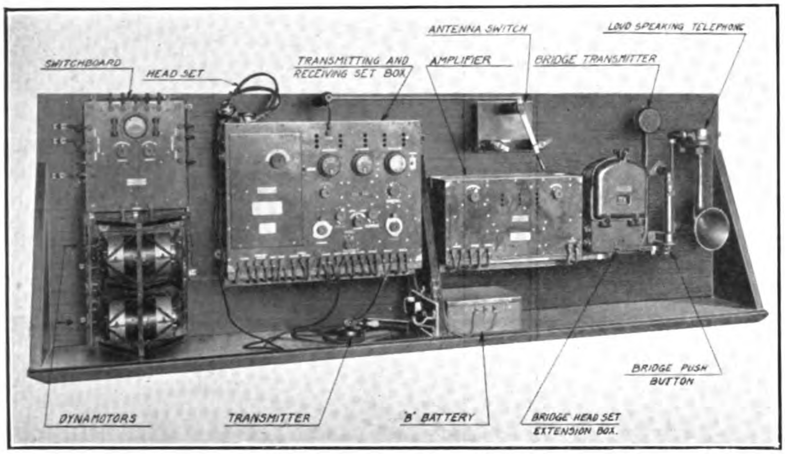
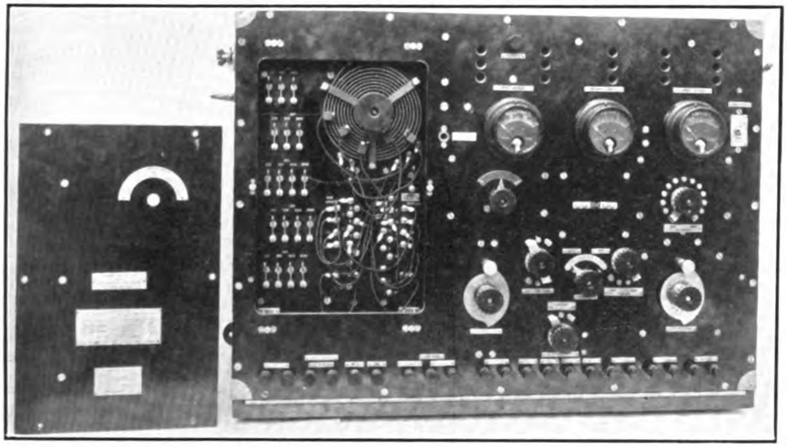


Fig. 42—Complete Western Electric Two-Station Radio Telephone Equipment for Submarine Chasers—Bureau of Steam Engineering Standard C W-936



[CRAFT & COLPITTS]

Fig. 43—Submarine Chaser Type Transmitting and Receiving Set Box—C W-936

entirely prevent reception. As a matter of fact, successful airplane telegraphy has been carried on in an experimental way by using the ignition magneto as a radio transmitter.

SUBMARINE CHASER EQUIPMENT

During the war important use has been made of the wireless telephone in connection with Naval work. Small 110-ft. craft had been largely employed in connection with anti-submarine operations. In order to make the most effective use of the various listening devices, and to co-ordinate the operations of the various units, it is very necessary that instantaneous and direct communication be established at all times. Under the direction of the Special Submarine Board of the Navy Department, modified forms of radio telephone equipment were developed for this purpose. Early in November 1917, the first practical trials were made, and satisfactory operation between chasers approximately five miles apart was obtained. These trials demonstrated the extreme value of this means of communication and sample equipments were immediately dispatched overseas for further trials under actual war conditions.

The circuits of this set are practically the same as the airplane equipment, except that power is obtained from small dynamotors operated from the 30 volt storage batteries with which the chasers are equipped. The set itself is located in the radio room, where it can be attended to by the regular radio operator. A telephone transmitter and receiver is, however, located in the pilot house so that the commanding officer can hold direct conversation with other vessels. The radio operator monitors the conversation and performs all tuning operations, thus leaving the commanding officer free to use the radio telephone as an ordinary wire line, except that he must press a button located at the side of the telephone when talking. The ordinary telephone head set is supplemented by a loud-speaking telephone receiver, which makes it possible for incoming signals to be heard without the use of head gear. Fig. 42 shows an assembled view of the various elements that go to make up a standard submarine chaser equipment. To provide sufficient energy for operating the loud speaking receiver a three-stage amplifier connected to the output side of the radio set is required. It is possible to connect the receiving portion of the radio set to either the ordinary head receiver or to the amplifier with its loud speaker.

Fig. 43 shows a close-up view of the radio transmitting and receiving set proper.

This equipment has an effective operating range of about ten miles when used on the 110-ft. submarine chasers. One feature not incorporated in the airplane sets consists of a wave length control gear by means of which the set can be operated on any one of five different wave lengths, ranging from 250 to 600 meters. This permits of a certain amount of selective operation within a chaser squadron.

A number of problems were met with in connection with this particular application not the least of which was the suppression of electrical disturbances in the antenna system due to the ignition system of the three propelling engines. Several thousand of these sets have been produced, and practically all submarine chasers sent overseas have been equipped with this apparatus. This apparatus is also being used for short range work on other types of naval vessels, with eminently satisfactory results. Modifications of the airplane type of equipment have also been made for use on naval seaplanes. For some classes of service the demand for longer range work has made necessary the employment of more powerful types of vacuum tubes.

The foregoing covers the most extensive application of vacuum tube radio telephony, the same general type of circuit and apparatus being used for short range telephony and telegraphy on land and water and in the air. For reasons already mentioned, quantity production has been limited to the earlier models, in spite of the fact that investigations carried on during production have indicated many changes which would improve the electrical and mechanical efficiency of the apparatus.

THE FUTURE OF RADIO-TELEPHONY

The possibility of communication by speech between any two individuals in the civilized world is one of the most desirable ends for which engineering can strive. For this reason it is particularly desirable to form some opinion of the part which radio telephony may play in securing this universal service. It is clear that the elimination of the Morse operator, which is accomplished by the use of radio telephony rather than radio telegraphy, is necessary for universal and direct communication.

Radio telephony and wire telephony offer several sharp contrasts. The latter requires fixed channels of communication whose construction and maintenance necessitates an accessible path between stations, but the results obtained include secrecy, power efficiency, selection of a desired station and freedom from interference. A large item of expense is the line. On the other hand radio telephony requires neither fixed nor accessible channels and no cost at all for line construction and maintenance, but it is non-secret in the practical sense of the word, its power efficiency is low, selection is at present not practicable except in a limited way by wave length, and freedom from interference is not at present an attained fact. Thus while the two systems may be contrasted they are not comparable but each is useful in its own field. It is easy to see that radio telephony can never compete with wire telephony in densely populated districts, while wire telephony is a physical impossibility at sea and in the air. Fortunately, however, the connection of a wire system to a radio system is no more complicated than connecting two wire lines by means of a repeater and therefore these two fields, although distinct, are adjacent. Leaving aside for the moment the particular methods by which radio telephone communication is to be carried on, it is clear that the establishment of communication between two given individuals will be most efficiently realized through the use of a combination of wire transmission on a network extending over perhaps 99 per cent of the stations and radio transmission to those relatively few stations to which it is either impossible or impracticable to build lines. These stations will be of two kinds:

1. *Moving*, such as ships, airplanes, trains, trucks.
2. *Fixed but inaccessible*, such as on islands, in deserts and in very sparsely settled regions.

A third class of service is that which is concerned, not with single individuals, but with groups; such service as the broadcasting of news, time and weather signals, and warnings. In some cases one objection to radio telephony would be an advantage in this class of service.

The choice of the particular kind of transmitting apparatus which will ultimately be used in thus extending the range of communication will involve careful consideration of costs and other engineering factors; its feasibility has, however, been conclusively demonstrated.

Presented at the 7th Midwinter Convention of the American Institute of Electrical Engineers, New York, February 21, 1919.

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TELEPHONE CIRCUITS WITH ZERO MUTUAL INDUCTION

BY WILLIAM W. CRAWFORD

ABSTRACT OF PAPER

The paper deals with the reduction of inductive interference in telephone circuits.

Various relative positions of two or more circuits, in which the mutual inductance is zero, and the mutual capacitance unbalance is approximately zero, are discussed. The most important case is that when the two wires of one circuit occupy opposite ends of one diagonal of a square, and the other circuit, the ends of the other diagonal. A phantom formed on circuits so related is nearly immune from external induction.

Several forms of construction embodying this arrangement, and built largely with standard parts, are illustrated. In these forms, about one third of the inductive relations of each physical circuit are with circuits in a position for approximately zero mutual inductance. The form of phantom transposition used automatically balances the circuits not so related.

Calculations and tentative designs are presented to show that the use of these forms of construction will give greatest refinement of balance against induction from power circuits, and possibly also against cross-talk, increased flexibility in coordinating with the variations in exposure to power circuits, a simplification of the transpositions system, fewer transposition poles and transpositions, and when desired, the realization of a part of these advantages with the lead compressed into less than the normal space. The improvement is greatest in the phantoms.

Adverse factors are the increased sensibility to cross-talk due to variations in sag, and the slightly increased capacitance of the phantoms.

The cost of initial construction of the proposed forms should not be materially higher than for the present standard form. The cost of conversion of an existing lead to one of the proposed forms will be considerably greater than that of re-transposing the lead according to present practises.

I. GENERAL

THE method of transposition as applied at present in telephone practise involves balancing against each other fairly large inductive effects in adjacent sections of the circuits. Mr. Harold S. Osborne has in a recent paper[1] named various influences which render it impossible to make the opposing effects completely annul each other. By proper design the

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Manuscript of this paper was received January 14, 1919.

residual unbalances are ordinarily reduced to a point which gives satisfactory operation. The design of the transposition system is, however, subject to severe limitations in the case where the telephone line is to parallel electric power circuits. Particularly, it is difficult to obtain proper co-ordination between the transpositions in the telephone circuits and the points where changes take place in the degree of exposure to power circuits.

There are certain relative positions of two or more circuits composed of parallel wires, in which the electrostatic and electromagnetic co-efficients of mutual induction are continuously zero. Between circuits so positioned not only should the residual effects disappear, but there should be no need for transposition. It seems worth while to inquire how far the employment of such arrangements will go toward giving greater refinement of balance, increasing the flexibility of design, and rendering usable for telephone leads locations which are not permissible in present practise. The idea involved is a very old one[2], and the aim of this paper is to show that it has certain merits in connection with modern practise which it did not have before the advent of the phantom circuit.

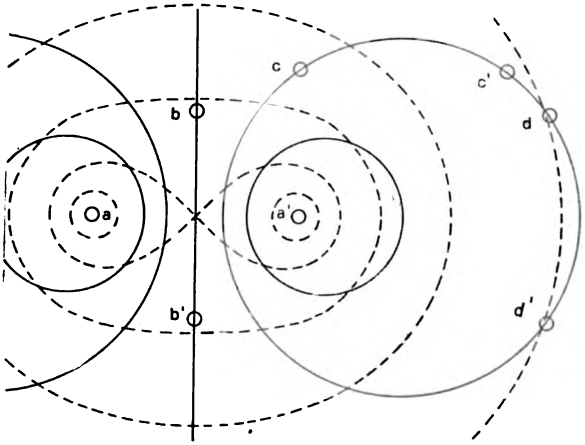

Fig. 1

In Fig. 1 the solid lines represent the electrostatic equipotential surfaces due to equal and opposite charges on the

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[1] Proceedings A. I. E. E., July, 1918.

[2] See A. V. Abbott, Electrical Transmission of Energy, 1898, Art. 52.

parallel wires $a\,a'$. Placing the two wires of the circuit $c\,c'$ in the same equipotential surface as shown, subjects both wires to the influence of the same potential, there is no tendency to induce a current around the circuit $c\,c'$. If, however, a and a' have like charges, the equipotentials are as shown by the dotted lines, c and c' are unequally affected.

A like situation arises with respect to electromagnetic induction. The lines of magnetic force due to a current out a and back a', or vice versa, follow the same curves as shown by the solid lines in Fig. 1. For such currents there is no mutual inductance between $a\,a'$ and $c\,c'$. But for currents travelling in the same direction along a and a', the lines of force follow the dotted curves, they link between c and c', and induce a current around that circuit.

The voice currents in the physical circuits travel around the circuits, but the phantom voice currents, and some classes of stray currents due to induction from outside sources, travel along both wires in the same direction. Therefore the arrangement of Fig. 1 would tend to eliminate cross-talk between the physical circuits $a\,a'$ and $c\,c'$, but not cross-talk between these circuits and a phantom set up on them, nor the tendency of stray lengthwise currents in one physical circuit to render the other physical circuit noisy. The latter effects are removed by treansposing both circuits alike.

The same is more or less true of every mutually non-inductive relative position of the two circuits except that shown by $a\,a'$ and $b\,b'$, Fig. 1. Wires $b\,b'$ lie in the same electrostatic equipotential, or link zero flux, for either like or unlike charges or currents on $a\,a'$. The circuit $a\,a'$ is also balanced for currents or charges in $b\,b'$. A circuit in the position $d\,d'$ is balanced with respect to $a\,a'$, but $a\,a'$ is only partially balanced with respect to $d\,d'$.

If a phantom is set up on the circuits $a\,a'$ and $b\,b'$ the, phantom is very nearly immune from external fields. The average effect of an external field on wires a and a' will approximately balance that on wires b and b', unless the field is very non-uniform. There is, moreover, no mutual induction between the phantom and its own side circuits—a marked contrast to present standard practise.

The above statements are inaccurate to the extent that the affected wires may have unequal capacities to ground, so that equal potentials induce unequal charges, and that the electrostatic field is distorted by the presence of otherwires on the lead, which behave as if grounded[3]. Consequently, there is no single relative position which will in all cases give perfect balance for both electrostatic and electromagnetic effects. Such transpositions as are necessary for other reasons, are sufficient to eliminate also these effects.

II. Application to Complete Leads

The practicability of applying the proposed group arrangement in practise will be discussed in terms of the forms of construction shown in Figs. 2 to 9 inclusive.

In form *A*, Fig. 2, the cross-arm spacing is made equal to the pin spacing. Wires 1 and 12 form a physcial circuit, as do the wires 2 and 11, all the other wires are arranged in similar groups. There is a considerable mutual induction between wires 1-12 and 4-13, also between 2-11 and 3-14. Between 1-12 and 3-14, 5-16, etc., there is an approach to the same relation as between *a a′* and *c c′*, Fig. 1.

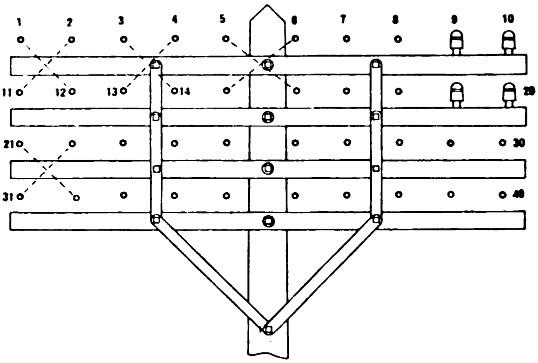

Fig. 2—Form *A*

There being no necessity of transposing the two physical circuits of a group relatively to each other, each group is treated as a unit in transposing relatively to the other groups. Special insulators or pins are not necessary to make a transposition. The wires are merely rotated around the quadrangle, for example, 1 replacing 2, 2 replacing 12, 12 replacing 11, and 11 replacing 1. For a physical transposition this rotation is continued in two spans, whereupon the two wires of each circuit are interchanged, see Fig. 3.

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[3] Loc. cit. page 767.

As shown in Table III, there is some mutual inductance between phantoms, though this is smaller than it is in the present system, and falls off much more rapidly with distance. The amount is sufficient to require transposition of the nearest phantoms. For a phantom transposition, the wires are rotated in only one span. This method transposition is the same as that now used in polyphase power circuits.

At the center of the span, the distance between the wires is reduced to $1/\sqrt{2}$ of its value at the poles, see dotted square in Fig. 3.

If existing crossarms are used to construct form *A* or *C*, the central group is not quite equilateral, there being a greater space between the pole pins. The chief effect of this distortion is to introduce into this one group a mutual inductance between the side circuits, about equal to that between a phantom and each of its side circuits in present practise, see Tables I and III. The phantom transpositions, by interchanging the pin positions of the side circuits, balance out this mutual inductance. Considerations of type unbalance between the side circuits may require transposing the phantom of this group to a pattern having more frequent transpositions than would be required for the benefit of the phantom alone.

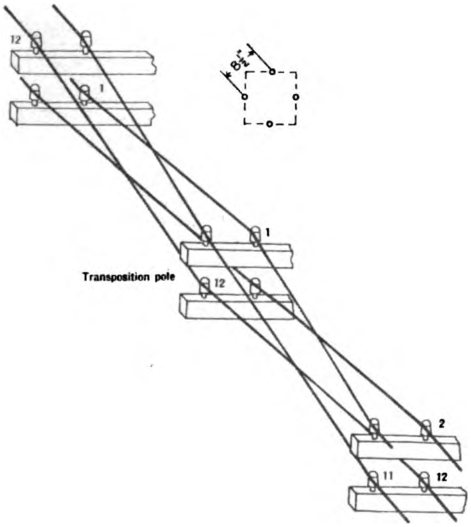

FIG. 3—PHYSICAL TRANSPOSITION

In form *B*, Fig. 4, the use of present standard crossarm spacing, as well as standard pin spacing, is contemplated. The only alteration required to convert a present type lead into form *B* would be to re-transpose, and re-connect the jumpers at the ends of the line. The mutual inductance between the side circuits, and the susceptibility of the side circuits to external induction appear, however, to be prohibitive, see Tables II and VII.

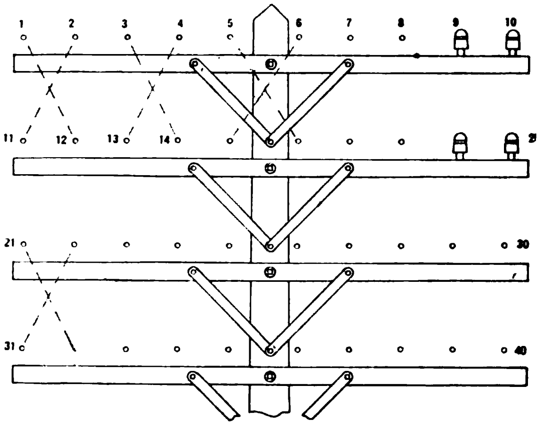

Fig. 4—Form *B*

Form *C*, Fig. 5, resembles form *A* except that the distance between the various horizontal rows of groups is increased, giving electrical characteristics somewhat better than form *A*, and better accessibility of the wires.

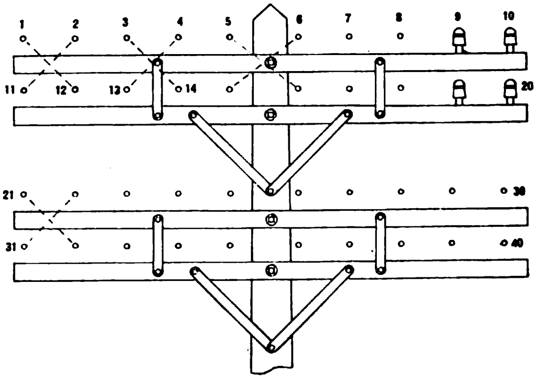

Fig. 5—Form *C*

In form *D*, Fig. 6, the aim is to provide still better conditions as to freedom from induction. The unsymmetrical center group is removed, and the spacing between the other groups is increased.

Form *E*, Fig. 7, is obtained by adding to a lead, constructed in accordance with present practise, four pairs of wires per crossarm, the added circuits being supported in vertical planes on special duplex pins or brackets. The necessity of having the lower wires clear the crossarm makes the groups unsymmetrical, but without introducing mutual inductance between the side circuits. The other inductive relations are affected as shown in Table I. The pole-pin wires may be reserved for non-phantomed circuits, or phantomed by the method now in use.

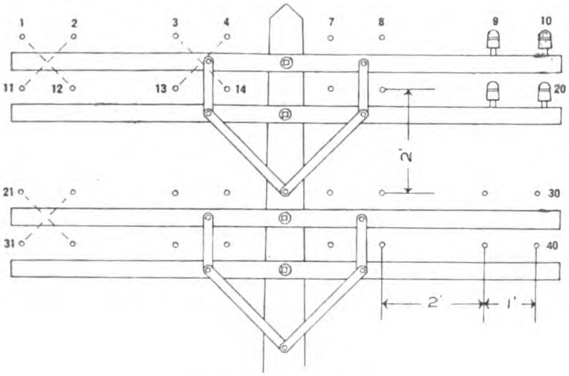

FIG. 6—FORM *D*

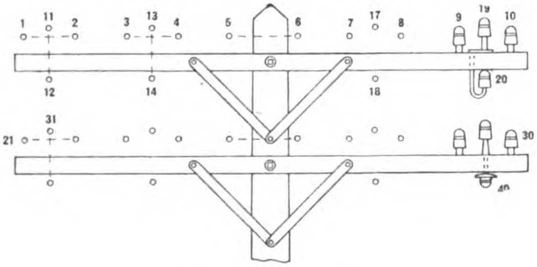

FIG. 7—FORM *E*

One or more form *E* groups may be incorporated in a lead which is otherwise standard, giving proper attention to the co-ordination of the transpositions of the two different styles of construction. The form *A* group may also be constructed with duplex pins or brackets, in which case it becomes feasible to use this form in the same way as the form *E*.

Form *F*, Fig. 8, is an idealised form *E*, in which the groups are symmetrical. Form *G*, Fig. 9, bears the same relation to form *F* that form *D* does to form *A*. On account of the small clearance between wires in form *F*, and *G*, standard crossarms cannot be used, and some special form of construction would have to be devised.

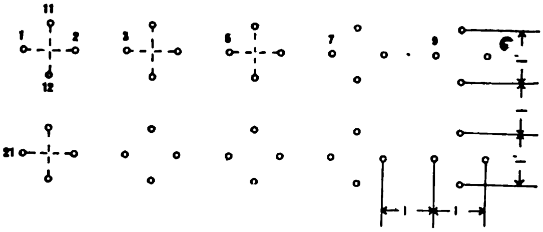

Fig. 8—Form *F*

Certain other designs, in which the form *A* group is alternated with the form *E* group, or in which the different horizontal rows of groups have different spacings, give zero mutual inductance between some of the adjacent phantoms. The possibilities presented by these designs have not yet been fully worked out.

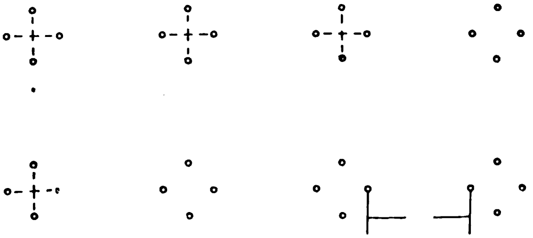

Fig. 9—Form *G*

III. Comparisons

In comparing the susceptibility to induction of the various forms it has unfortunately been possible to take account only of the mutual inductance, and not of the capacitance unbalances, because of the great labor required to compute the latter[4]. Probably the two effects will vary nearly enough in the same proportion, as between different forms, so that the comparisons on a basis of inductance alone, if used with due caution, will not give false conclusions. Values of mutual inductance are given in Tables I, II, and III.

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[4] Loc. cit. page 744.

In form *A*, the maximum value of mutual inductance (that between circuits related like 1-12 and 4-13) is about equal to that between a phantom and one of its own side circuits, or between two vertically adjacent horizontal type phantoms, in present practise. Each physical circuit other than the pole-pin circuits in form *A* has two or three such relations. The pole-pin circuits have one additional large value. In the standard form, the large value comes only once into each physical circuit, but three or four times into each phantom, except the pole-pin circuits and phantom. Form *A* therefore decreases the induction between phantoms at the expense of the physical circuits.

In form *C*, the maximum value of mutual inductance is the same as in form *A*, but this value occurs less frequently.

Forms *D*, *F*, and *G* give on the whole a very great reduction in mutual inductance. Forms *F* and *G* are interesting from the large number of values of zero mutual inductance which they afford. Most of these are due to the relation *a a'* to *d d'*, Fig. 1.

Form *E* has a large value of mutual inductance, about equal to that in the standard form, which comes once into each phantom, and once each into half the side circuits.

A summation was obtained of the inductive effects on each circuit of all the other circuits (Table IV and V), showing that the phantoms in the proposed forms are on the average about one tenth as sensitive to cross-talk as are the side circuits. In the standard form the phantoms are twice as sensitive as the side circuits. Although the sensitivity of the side circuits is increased in form *A*, the reduction of the sensitivity of the phantoms is sufficient to make the average for all circuits less than in the standard form, despite the fact that in form *A* a given number of circuits are compressed into half the normal space. Such a compression of the standard form would result in considerable increases in the mutual inductance values, with consequent increase of the sensitivity to cross-talk. In form *C* the sensitivity of the side circuits is about the same as in the standard form, the improvement of the phantoms is clear again. In the other forms, the sensitivities of side circuits as well as phantoms, are decreased.

Corresponding figures (Table VII) for the sensitivity to induction from power circuits show a similar result. In forms *A*, *C*, and *D*, the sensitivity of the side circuits is increased because in these forms the distance between the two wires of a side circuit is *V* 2 times what it is in present practise. The sensitivity of the phantoms is, however, negligible, except when the disturbing circuit is very close to the telephone circuit.

On account of the shorter average distance between the wires in a group in the proposed forms, it is to be expected that the effect of accidental displacements of the wires from their correct positions will be greater than in standard practise. The unbalance produced will in each case be greatest between the cirucits forming one group, and the comparison is made only on the basis of such circuits. (Table VI).

For horizontal displacements, the various forms have nearly the same sensitivity as standard construction. Horizontal displacements should be rare, because the horizontal spacing is fixed by the pin locations.

The effective vertical spacing depends on the sag, and this is likely to vary. For displacements as small as the value assumed for comparison (root-of-mean-square displacement, 0.1 foot, or 0.03 meter) the effect is practically nil in the standard form, but in all the proposed forms, it is appreciable. This is a distinct disadvantage, the importance of which can be determined only by the aid of data from actual construction. Comparison with the values in Table V appears to show that unless the r. m. s. value of displacement is considerably greater than the value assumed, the total unbalance due to these displacements will not be more serious than the unbalance which occurs in standard practise due to the transpositions being located at the nearest poles, instead of at the theoretically correct points. The tendency of the proposed forms being to reduce the effect of inexact location of the transpositions, the total effect of all irregularities should not be much greater than in present practise.

Keeping the crossarms carrying wires in the same groups accurately parallel is evidently essential in forms *A*, *C*, and *D*, the method of bracing illustrated in these forms is intended to provide for this.

The effect of displacements of the wires on the induction from power circuits is the same in the proposed forms as in the standard form.

Number of Transpositions and Number of Transposition Patterns. Certain comparisons are fairly obvious between the number of transposition patterns (types) and the total number of transpositions required in the standard and proposed forms.

The condition of zero mutual induction between a phantom and its side circuits does not mean that the three circuits can be transposed after the same pattern. If that were done, each time a side circuits reversed, it would move to the other pin position, for a given pin position it would always have the same polarity, it would not be balanced with respect to external induction. This fact is exemplified in the standard *E*-section[4] in circuits 5-6 and 15-16, which have zero mutual inductance with the phantom, nevertheless, they are transposed to different patterns from the phantom (Table IX).

If each circuit is to have its own transposition pattern, thirty patterns are required for the commonly used physical and phantom circuits on the first four arms in the standard form. In the proposed forms, each pair of side circuits being transposed as a unit, only twenty patterns would be required.

In the *E*-section, 16 types of transposition pattern are used, and mutual inductance and capacitance unbalances as large as 5.44 microhenries per kilometer, and 3.0 micro-microfarads per kilometer, respectively, are allowed. Adopting these limits for the proposed forms permits a still further reduction in the number of patterns, and in the number of transpositions, required.

The effect of simultaneous phantom transpositions in two groups is to reverse the mutual inductance between the circuits whose planes are at right angles, like 1-12 and 4-13, Figs. 2, 5, or 6. Only the circuits related like 1-12 and 3-14 are left unbalanced, and the mutual inductance between these is small. Whenever the mutual inductance of two phantoms is small enough so that they can be transposed to the same pattern, the same is true of the physical circuits.

Fig. 10 shows a transposition system which utilized this fact. Four types of group transposition are used, denoted by I, II, III, IV. There are only sixteen transposition poles per section. The procedure in design was as follows:

Physical transpositions were inserted in all the groups at the odd-numbered transposition poles, balancing the physical circuits for outside induction every eighth section. Next, phantom transpositions were inserted at the poles 2, 6, 10, and 14. This balances the phantoms every quarter section for sources of induction which are too near for the phantoms to be immune due to their form. As already stated, these phantom transpositions greatly reduce the unbalance between physical circuits. Poles 4, 8, and 12 remain for balancing out the induction between phantoms and the residual induction between physical circuits in the four groups. Only two phantom types are used, leaving the diagonally adjacent phantoms untransposed. It is then possible to obtain complete balance of the four adjacent pairs of physical circuits. There are several ways of doing this, one of which is shown. It is also possible to balance the four phantoms, leaving a slight residual unbalanced in the diagonally adjacent pairs of physical circuits.

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[4] Loc. cit. page 753, Fig. 5.

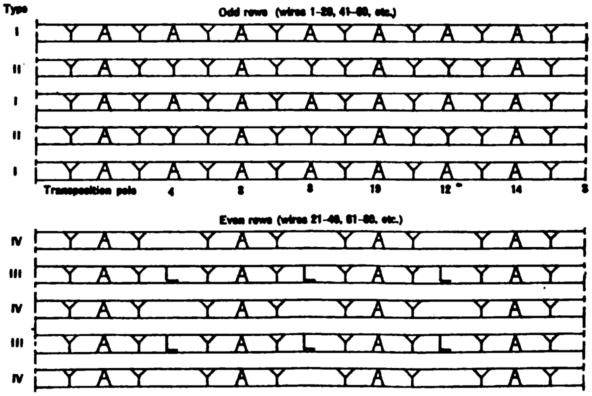
Type
Odd rows (wires 1-20, 41-60, etc.)
I
II
I
II
I
Transposition pole
4
6
8
10
12
14
Even rows (wires 21-40, 61-80, etc.)
IV
III
IV
III
IV
Y
A
L

FIG. 10

Y—physical transposition
A—phantom transposition, right-handed
L—phantom transposition, left-handed

The largest values of unbalanced mutual inductance in Fig. 10 are as follows:

Form	*A*	*C*	*D*	*F*	*G*
Diagonally adjacent groups					
Phantoms	4.77	0.76	0.93	1.17	0.23
Alternate groups in the same horizontal row					
Phantoms	1.17	1.17	0.23	0.29	0.06
Physical circs.	1.55	1.55	0.31	0.40	0.08

Limits in the standard *E*-section
Inductance unbalance, 5.44, capacitance unbalance, 3.0

The inductance unbalance is within the limit even for form

A. The limiting value of capacitance balance in the *E*-section, however, occurs between circuits which are separated by a large number of intervening wires, the screening action of which has a large effect in reducing the capacitance unbalance. There will be very little screening action between the diagonally adjacent groups in the proposed forms, hence, in form *A* the capacitance unbalance between the diagonally adjacent phantoms will be much too large if Fig. 10 is used. In the other forms, however, the inductance unbalances are so far below the limit that it is probable that the capacitance unbalances are not excessive, and Fig. 10 can be used.

Fig. 11 shows a system in which the mutual inductance between the diagonally adjacent phantoms is eliminated. The method of design was the same as in Fig. 10, except that physical balance was obtained between horizontally and vertically adjacent groups at the outset, giving the necessary added flexibility to permit transpositions on poles 4, 8, and 12 to completely balance the four groups. In this case, the maximum unbalance is between alternate groups in the same horizontal row. Fig. 11 is apparently suitable for use with form *A*. By using a slightly larger number of transpositions, with the same number of transposition poles, non-adjacent groups can be completely balanced if desired.

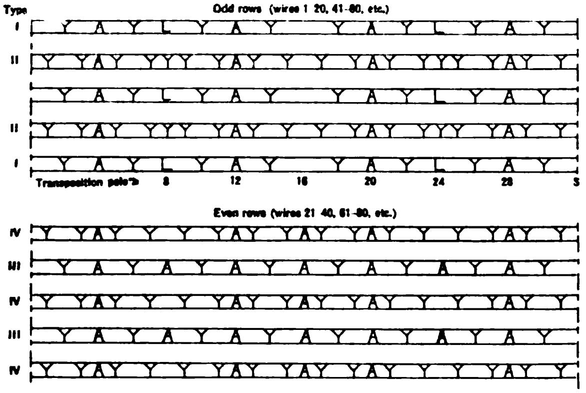
Type
Odd rows (wires 1 20, 41-60, etc.)
I
II
II
I
Transposition poles
8
12
16
20
24
28
S
Even rows (wires 21 40, 61-80, etc.)
IV
III
IV
III
IV
Y
A
L

FIG. 11

Y—physical transposition
A—phantom transposition, right-handed
L—phantom transposition, left-handed

The extension of Figs. 10 and 11 to more than forty wires is a matter only of repeating the same system, additional transposition poles are not necessary.

These designs were not obtained by a systematic study of all the possibilities, but rather, by a logical process from the assumed conditions, to which method the proposed form of construction appears to be favorable. The designs are of a tentative nature, and are intended merely as illustrations of the possibilities of the proposed forms.

In standard practise, a distinction is drawn between the effect of distant and near disturbing circuits, on account of the effect of the phantom transpositions in shifting the pin positions of the physical circuits. In Figs. 10 and 11, this effect does not need to be considered, since each section of physical circuit between two phantom transpositions is completely balanced for external induction. The distinction between near and distant circuits is in the proposed forms based on the phantoms, the balance of which with respect to distant circuits is not dependent on transpositions.

COMPARISONS OF DESIGNS FOR TRANSPOSITION SECTIONS

	Standard	Proposed	
	E-section	Fig. 10	Fig. 11
No. of transposition poles per section			
First 40 wires	32	16	32
Additional wires	64	16	32
No of transpositions per section, 40 wires	288	141	179
Wires cut	876	564	716
Balanced to distant non-transposed circuits, every	Eighth-section. Eighth-section.	Eight-section. Eighth-section.	Eighth-section. Eighth-section.
Balanced to near non-transposed circuits, every	Half-section.	Quarter-section.	Quarter-section.
Balanced to distant 3-phase power circuits for	Two successive half-mile barrels. 3, 6, or 12-mile barrels.	Single half-mile barrels. 3, 6, or 12-mile barrels.	Two successive half-mile barrels. 3, 6, or 12-mile barrels.
Balanced to near 3-phase power circuits for	Quarter-mile barrels, 12-mile barrels.	Quarter or half-mile barrels, 6 or 12-mile barrels.	Quarter-mile barrels, 6 or 12-mile barrels.
Neutral points for discontinuities of telephone lead.	*S* poles	*S*-poles	*S* poles, half-section points.
Balance for a half-section, equal to Fig. 10 for a whole section.			

The permissible locations for discontinuities of the telephone lead depend a good deal on the form of construction. For example, a form *D* lead transposed by Fig. 10 or 11 could be discontinued at a half-section, or even at a quarter-section point, with only a very slight resultant unbalance.

Provision for Non-Phantomed Circuits. Where non-phantomed circuits occur in pairs, they may be treated in the same manner as phantomed circuits, except, possibly, in the case of circuits which have transmitters of large output, in which the unbalance due to sag variations may make it undesirable to associate the circuits in groups of the proposed form. Each single non-phantomed circuit will have to occupy the space appropriate for a group. If there are only a few such circuits, the loss of space will be small, for a larger number, one or more crossarms of standard construction may be incorporated in the lead.

Effects of the Constants of the Circuits. The capacitance of the phantoms is about 30 per cent greater in the proposed forms than in present practise, and the inductance correspondingly less. The change in the constants of the side circuits is very slight.

Cost. On account of the necessity of re-spacing the crossarms, or of providing special insulator supports, the cost of converting from the standard form to one of the proposed forms is evidently in general considerably greater than that of re-transposing a standard form lead. The cost of converting to form *E* with an increased number of circuits may in some cases be less than that of providing the additional circuits by the standard method.

For initial construction of forms *A* or *C* there would apparently be no increased cost for materials, and a saving in the cost of transposing. Form *D* presents a slight increased cost of materials, due to the increased number of crossarms per circuit-mile.

IV. CONCLUSIONS

The anticipation that the use of the proposed forms of telephone line construction and transposition under exposed-line conditions will give greater refinement of balance and increase the flexibility in co-ordinating with transpositions and discontinuities of the disturbing circuits, particularly, when the telephone circuits are phantomed, appears to be justified.

The proposed forms appear to be especially well adapted for use on joint pole lines and in other cases of severe or irregular exposure. Obviously, they affect only the particular phases of inductive interference for which transposition is a remedy. The worst effect of severe exposure to power circuits is that of the high longitudinal electromotive forces and currents induced in the telephone circuits when an adjacent power circuit operates normally with a ground return, or is accidentally grounded[5]. The increased balance of the open-wire circuits afforded by the proposed forms should permit operating with larger values of longitudinal currents than in the standard form, except where the limiting value of the current or e. m. f. is determined by conditions of safety, or by the balance of the terminal apparatus.

Present-type phantoms are often used as parts of longer lines, despite the fact that they are considerably more susceptible to noise and cross-talk than are the physical circuits, and that a given amount of noise is of greater importance in the longer circuit. The proposed forms in which the phantoms are relatively immune from disturbances, bring the desirable qualities of noiselessness and good transmission together in the circuits where they are most needed.

Form *A* is for use in new construction where space limitations are extreme.

Form *C* permits an appreciable saving of space, with a good degree of balance, a saving in the number of transpositions and transposition poles, and increased flexibility in the location of discontinuities in power circuits, as compared to the standard *E*-section.

Form *D* gives a considerable reduction of type unbalance and unbalance due to unequal transposed lengths, with a slight increase of cost, as compared to form *C*.

Partial or complete conversion to form *E* recommends itself when it is desired to route one or more high-grade phantom circuits through locally adverse conditions, or where it is desired to add a few circuits to the lead under conditions of limited space. Partial conversion to form *A*, *C*, or *D*, may also be effected; in these forms, the phantoms have better balance than in form *E*. Such conversion is of course conditional on the ability of the crossarms to support the additional weight.

Forms *F* and *G* promise the highest degree of balance of all the forms shown, but would probably not be considered in the present state of the art on account of the special construction required.

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[5] "Transposition and Relative Location of Power and Telephone Wires," P. M. Lincoln, Trans. A. I. E. E., 1903.

"Inductive Effects, etc.," H. S. Warren, Trans. A. I. E. E., Aug., 1918.

V. Numerical Values and Methods of Calculation

a. *Mutual Inductance.* The calculations were made on the basis of a spacing between the pole pins equal to that between the other pins, except in forms *D* and *G*, where the distance between groups was made uniform. The order of magnitude of the differences due to these assumptions is indicated in Table I. Where the differences are large enough to affect the comparisons appreciably, allowance has been made for them.

From the values given in Tables I, II and III, the mutual inductances of most of the other pairs of circuits can be found, by determing to which of the circuits given in the table, their relative location is similar.

TABLE I

EFFECT OF ASSUMPTIONS AS TO SPACING

Circuits	Mutual inductance, microhenries per kilometer	
	Actual	Assumed
Standard Form		
1-2 and 5-6	-16.00	-12.92
1-2 and 9-10	-2.92	-3.13
Forms *A* and *C*		
5-16 and 6-15	-115.08	0
Phants. 3-14-4-13 and 5-16-6-15	-19.38	-17.86
Phants. 3-14-4-13 and 7-18-8-17	-0.84	-1.17
Forms *E* and *F*	Form *E*	Form *F*
1-2 and 13-14	-15.58	0
Phant. and its own vertical side	122.38	0
Phants. 1-2-11-12 and 3-4-13-14	9.87	4.77
Phants. 1-2-11-12 and 21-22-31-32	-0.40	4.77

b. *Summated Effects of Unequal Transposed Lengths and Type Unbalance.* The summation of these effects was obtained as follows:

Assume a given circuit to be affected by equal values of current I and equal unbalanced lengths l in all the other circuits. The voltages induced will be

$$E_2 = -jM_2\,\omega_2\,I_2\,l$$
$$E_3 = -jM_3\,\omega_3\,I_2\,l$$
etc.

and if the frequencies are nearly equal, the energies induced in the first circuit by the various other circuits will be proportional to

$$E_2^2,\ E_3^2,\ \text{etc.}$$

The total energy will be proportional to ΣE^2, or, since $j\ I\ \omega\ l$ is assumed to be constant, to ΣM^2. ΣM^2 is therefore a measure of the total sensitivity of the circuits to electromagnetic induction from the other circuits. For a complete result, of course, a like value for electrostatic induction should be obtained.

TABLE II

MUTUAL INDUCTANCES BETWEEN PHYSICAL CIRCUITS

Microhenries per Kilometer.

Form of construction								
Present		Proposed *A*		*B*	*D*	*F*		*G*
Effect on physical circuit 1-2		1-12		1-12	1-12	1-2		1-2
Of Circ.	*M*	Of Circ.	*M*	*M*	*M*	Of Circ.	*M*	*M*
3-4	-57.54	2-11	0	277.3	0	11-12	0	0
5-66	-12.92	3-14	22.31	140.2	4.82	3-4	-57.54	-23.55
7-8	-5.64	4-13	102.17	-81.1	44.63	13-14	0	0
9-10	-3.16	5-16	1.55	38.7	....	5-6	-12.92	-5.63
11-12	44.63	6-15	25.03	57.5	....	15-16	0	....
13-14	1.55	7-18	0.31	17.1	0.31	7-8	-5.64	-5.64
15-16	-5.92	8-17	11.11	60.4	11.11	17-18	0	0
17-18	-4.02	9-20	0.09	9.5	0.07	9-10	-3.16	-2.47
19-20	-2.61	10-19	6.26	15.3	4.93	19-20	0	0
21-22	12.12	21-32	22.31	-32.5	4.82	21-22	44.63	21.08
23-24	6.07	22-31	-102.17	-69.7	-44.63	31-32	0	0
25-26	4.03	23-34	-57.54	-57.5	-23.55	23-24	1.55	0.30
27-28	-1.54	24-33	0	-28.4	0	33-34	-25.04	-11.11
29-30	-1.49	25-36	-16.25	-25.6	....	25-26	-5.92	......
31-32	5.48	26-35	11.99	1.4	....	35-36	-8.01	....
33-34	3.98	27-38	-6.92	-9.3	-6.17	27-28	-4.02	-2.66
35-36	1.52	28.37	8.00	7.8	5.33	37-38	-3.00	-3.56
37-38	0.01	29-40	-2 72	-3.2	-2.66	29-30	-2.61	-1.78
39-40	-0.56	30-39	5.19	7.6	3.55	39-40	-1.38	-1.25
Effect on		2-11		....	2-11	11-12		11-12
		Of	*M*		*M*	Of	*M*	*M*
		26-35	15.69	....	....	19-20	3.12	1.78
		28-37	6.06	....	7.05	25-26	6.06	....
		30 39	2.81	....	2.67	27-28	....	5.48
Form *C*. First row like Form *A*. Second row:								
Effect on		1-12		1-12		2-11		
		Of	*M*	Of	*M*	Of	*M*	
		21-32	4.82	26-35	4.46	24-33	26.83	
		22-31	-44.63	27-38	-7.17	28-37	7.05	
		23-34	-30.15	28-37	5.33	26-35	14.84	
		24-33	-11.78	29-40	-3.60	30-39	3.61	
		25-36	-15.93	30-39	4.13			

ΣM^2 may be taken for each pair of circuits on the lead, and the average per circuit or per group taken as representing the whole system.

The induced e. m. f. or current due to type unbalance is, for a given relative transposition type, also proportional to the co-efficient of mutual induction. ΣM^2 may therefore be considered to represent in a measure the total effect of type unbalance, although the comparison will be affected to some extent by the practise of reducing the effect of large values of

TABLE III

MUTUAL INDUCTANCE BETWEEN PHANTOMS AND BETWEEN PHANTOMS AND PHYSICAL CIRCUITS

Microhenries per Kilometer

Form of construction Present Effect on phantom 1–2–3–4		Proposed *A* 1–12–2–11	*D*	*F*	*G* 1–2–11–12		
Of Phantom	*M*	Of Phantom	*M*	Of Phantom	Of Phantom	*M*	*M*
5–16	-60.02	3–13	-17.86	-3.64	3–14	4.77	0.93
7–10	-24.75	5–15	-1.17		5–16	0.29	
11–14	117.34	7–17	-0.23	-0.23	7–18	0.06	0.06
17–20	-18.88	9–19	-0.08	-0.04	9–20	0.03	0.01
21–24	41.35	21–31	-17.86	-3.64	21–32	4.77	0.93
25–36	-19.90	23–33	4.77	0.93	23–34	-1.17	-0.23
27–30	-5.34	25–35	0.21		25–36	-0.05	
31–34	20.38	27–37	-0.05	0.04	27–38	0.02	-0.01
37–40	2.28	29–39	-0.03	-0.01	29–40	0.01	0.003
Of Phy. Circ.		Of Phy. Circ.			Of Phy. Circ.		
1–22	109.86	1–12	0	0	1–2	0	0
3–4	109.86	2–11	0	0	11–12	0	0
5–6	-58.78	3–14	-29.39	-8.12	3–4	14.32	3.96
7–8	-28.77	4–13	-29.39	-8.12	13–14	0	0
9–10	-8.51	5–16	-3.31		5–6	1.62	
11–12	47.78	6–15	-3.31		15–16	0	
13–14	47.78	7–18	-0.95	-0.95	7–8	0.46	0.46
15–16	-7.66	8–17	-0.95	-0.95	17–18	0	0
17–18	-9.97	9–20	-0.40	-0.28	9–10	0.20	0.14
19–20	-6.54	10–19	-0.40	-0.28	19–20	0	0
21–22	19.28	21–32	-29.39	-8.12	21–22	0	0
23–24	19–28	22–31	29.39	8.12	31–32	-14.32	-3.96
25–26	5.45	23–34	14.32	3.96	23–24	-3.31	-0.95
27–28	-1.84	24–33	0	0	33–34	3.31	0.95
29–30	-3.02	25–36	1.78		25–26	0.18	
31–32	9.79	26–35	-2.45		35–36	-1.08	
33–34	9.79	27–38	0.18	0.54	27–28	0.22	0.06
35–36	5.42	28–37	-1.08	-0.75	37–38	0.32	0.32
37–38	1.38	28–40	-0.03	0.06	29–30	0.14	0.07
39–40	-0.62	30–39	-0.50	-0.32	39–40	0.12	0.10

M by more frequent transposition, which practise may be favored by one form of construction more than another.

TABLE IV

VALUES OF ΣM^2 BY CIRCUITS

$$\frac{\text{Microhenries}}{\text{Kilometer}} \div 10{,}000$$

Standard Form							
Wires	1–2		3–4	5–6	7–8		9–10
Sides	2.10		2.89	1.66	2.89		2.10
Phants		5.51		4.01		5.51	
Wires	11–12		13–14	15–16	17–18		19–20
Sides	2.54		3.39	1.87	3.39		2.54
Phants		7.51				7.51	

For the lower two cross-arms, use the same values in the reverse order.

Form *A*					
Wires	1–12	3–14	5–16	7–18	9–20
Sides	2.84	4.22	5.64	4.22	2.70
Wires	2–11	4–13	6–15	8–17	10–19
Sides	2.70	4.22	5.64	4.22	2.84
Phants	0.44	0.67	0.67	0.67	0.44

For the second row of groups, put 21–32 for 2–11, 22–31 for 1–12, etc.

Form *D*					
Wires	1–12	3–14		7–18	9–20
Sides	0.50	0.74		0.75	0.49
Wires	2–11	4–13		8–17	10–19
Sides	0.49	0.75		0.74	0.50
Phant	0.034	0.050		0.050	0.034

For the second row of groups, put 21–32 for 2–11, 22–31 for 1–12, etc.

Form *F*					
Wires	1–2	3–4	5–6	7–8	9–10
Sides	0.65	1.06	1.08	1.06	0.65
Wires	11–12	13–14	15–16	17–18	19–20
Sides	0.64	0.80	0.92	0.80	0.64
Phants	0.049	0.073	0.074	0.073	0.049

Second row of groups, same values.

Form *G*					
Wires	1–2	3–4		7–8	9–10
Sides	0.120	0.188		0.188	0.120
Wires	11–12	13–14		17–18	19–20
Sides	0.120	0.175		0.175	0.120
Phants	0.004	0.006		0.006	0.004

Second row of groups, same values.

The values of ΣM^2 in Tables IV and V are found for a 40-wire lead except in forms *D* and *G*, where 32 wires are assumed.

The values for form *C* in Table V were estimated by combining the values in Table IV for forms *A* and *D*.

The improvement in forms *F* and *G* over *A* and *D* respectively shown in Table V, is found to be due primarily to the reduced size of the square on which the wires are spaced. Like results could be obtained in forms *A* and *D* by a corresponding reduction in the minimum distance between wires.

c. *Effect of Accidental Variation in Spacing.* A given displacement of one wire in a group in general changes the mutual inductances between the side circuits and between each side circuit and the phantom. If M represents a change of mutual inductance, the sensitivity of the group to these effects may be expressed as $(\Sigma M)^2$, where the summation is taken over the three circuits and the two inductive relations for each.

TABLE V

Average $\Sigma M^2 \div 10{,}000$

Form	Physical circuits	Phantom circuits	Per group
Standard	2.52	6.01	11.05
A...........	3.92	0.58	8.42
C...........	2.82	0.42	6.06
D...........	0.62	0.042	1.28
F...........	0.83	0.0644	1.72
G...........		0.005	0.307

The effects of opposite directions of displacement are averaged. In the standard form, the effect depends on whether wire 1 or 2 is displaced, the values given are averages for displacements of the two wires.

In forms *E*, *F*, *G*, for the effect of displacements of wires 11–12, interchange columns 2 and 3. The average for vertical displacements of any one of the four wires is 0.238 per group.

The reasoning in arriving at the relative importance of sag variation and other sources of unbalance was as follows:

On the assumption that the displacements follow the probability law for errors, the resultant value of M for a considerable number of spans will be the square root of the sum of the squares of the values for the individual spans. The value of $(\Sigma M)^2$ for n spans will then be n times the average value for one span. Dividing the value of ΣM^2 for a group in the standard form, viz, 11.05 by the values of $(\Sigma M)^2$ in Table VI therefore gives the number of spans in which the displacement effect must occur to be the equivalent of one span of unbalanced length in the standard form. This is 91 spans for forms *A*, *C*, and *D*, and 46 spans for forms *E*, *F*, and *G*. In the *E*-section, the frequently-used transposition patterns have only 14 to 40 spans per transposition. At each of these transpositions there is a liability to one span unbalance, assuming that the transposition have not been set exactly at the correct points. In a long line these unbalances will add by the same law as the displacement unbalances and will produce a greater total unbalance than that due to sag variation unless the r. m. s. displacement is considerably larger than the value assumed. The value of $(\Sigma M)^2$ due to displacements of all four wires appears to be about the same as that for dis-

TABLE VI
EFFECT OF DISPLACEMENTS
Standard of Comparison, effect of displacing one wire 3 cm. (0.1 foot)
Values of $(\Sigma M)^2 \div 10{,}000$

Circuit of which one wire is displaced, marked		
Effect on circuit	Horizontal displacement	Vertical displacement
Standard Form		
1-2	0.043	Less than 0.001
3-4	0.015	"
Phant	0.034	"
Group	0.092	"
Forms *A*, *C*, *D*		
1-12	0.051	0.051
2-11	0.051	0.051
Phant	0.020	0.020
Group	0.122	0.122
Forms *E*, *F*, *G*		
1-2	0.040	0.158
11-12	0	0.198
Phant	0.040	0.040
Group	0.080	0.396

placements of only one wire, due to the large number of cases in which the displacements of two or more wires compensate each other.

The effect of turning corners is to reduce the horizontal spacing without affecting the vertical spacing. A 52 deg. turn (Fig. 12) is required to reduce the horizontal spacing by 10 per cent. in a whole span. The value of $(\Sigma M)^2$ due to this distortion is zero, within the group, for standard construction, and for forms *E*, *F*, and *G*. In forms *A*, *C*, and *D*, it is as follows:

Per physical circuits	0.177
Per phantom circuit	0
Per group	0.354

The effect is always in the same direction until a phantom transposition is reached, when it is reversed. Consequently the total effect varies as the square of the number of corners. There would have to be an unbalance equivalent to five or six 52 deg. turns of the style shown in Fig. 12, between successive phantom transpositions, in order to equal the unbalance of $\Sigma M^2 = 11.05$ which may occur in standard practise due to transposition poles not being located at the exactly correct points.

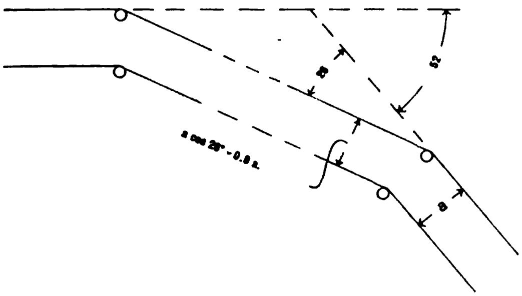

FIG. 12

d. *Induction from Power Circuits.* Following a reasoning analogous to that for cross-talk, the sensitivity of a given circuit to induction from a power circuit is taken as proportional to average E^2, where E is the voltage induced in the telephone circuit by a standard value of I in the power circuit, and the average is taken for every relative direction of the power circuit from the telephone circuit. Assuming a constant frequency, average E^2 is proportional to average ϕ^2, where ϕ is the flux through the telephone circuit due to unit current in the power circuit. For the effect of a single wire on a physical circuit,

$$\phi = 2\,\frac{a^2}{d^2}\cos\phi \tag{1}$$

and

$$\text{avg. }\phi^2 = 2\,\frac{a^2}{d^2}\text{, approximately} \tag{2}$$

where *a* is the distance between the wires of the telephone circuit and *d* is the distance of the power wire from the center of symmetry of the telephone circuit, and *θ* is the angle between *a* and *d*.

TABLE VII.

ELECTROMAGNETIC INDUCTION FROM POWER CIRCUITS, SINGLE WIRE AT DISTANCE OF 1.5 METERS (5 FEET)

Form	Circuit	a feet	Avg. ϕ^2	
			Per circ.	Per group
Standard	Physical	1	0.08	
	Phantom	2	0.32	0.48
A, C, D	Physical	√2	0.16	
	Phantom	√2	0.0008	0.321
F, G	Physical	1	0.08	
	Phantom	1	0.0002	0.160
B	Physical	√5	0.4	0.8

For a present type phantom, formulas (**1**) and (**2**) are used, assuming that the phantom is made up of two circuits in parallel For the proposed phantoms,

$$\phi = \frac{a^2}{2d^2}\cos 2\phi \tag{3}$$

$$\text{avg. }\phi^2 = \frac{a^4}{8d^4} \tag{4}$$

where *a* is the diagonal of the group, and *d* and *θ* are as before. Comparative values are given in Table VII.

In form *E*, the distortion of the group increases average ϕ^2 for the phantom by 0.01, making the total for the group 0.17.

The above values represent also a reduction in the amount of noise induced in a given phantom by stray longitudinal currents in the other wires of the telephone lead.

e. *Characteristics of Standard E-Section.*

In the following table, M_I is the mutual inductance, in microhenries per kilometer, computed from Table II, and M_C the mutual capacitance unbalance, in micro-microfarads per kilometer, computed from the table given by Osborne[6]. In computing both M_I and M_C account was taken of the two pin positions of each physical circuit.

f. *Computation of Unbalances in Proposed Forms.* In Fig. 2, let the mutual inductance (or capacitance unbalance) between the physical circuits of one group (say 1–12–2–11) and another group (say 3–14–4–13) be represented as follows:

TABLE VIII.

Type	Transp. per Section	Circuits		M_I	M_C
		Physical	Phant.		
i	23	5–6	37–40	5.44	0.08
j	22	...	5–16	....	...
k	21	15–16	31–34	5.44	0.8
l	20	13–14, 27–28	.....	−4.14	2.5
m	19	29–30, 31–32	.....	−4.14	2.4
n	18	9–10, 23–24	.....	−0.14	0.6
o	17	1–2	27–30	−2.43	3.0
p	16	7–8	21–24	−2.43	3.0
A	15	11–12, 39–40	.....	−0.14	0.6
B	14	19–20, 21–22	.....	−4.14	2.6
C	13	... ...	25–36	....	...
D	12	3–4, 17–18	.....	−4.14	2.8
E	11	37–38	11–14	−2.43	2.3
F	10	35–36	7–10	5.44	0.8
G	9	25–26	1–4	5.44	0.8
H	8	33–34	17–20	−2.43	2.2

Between 1–12 and 3–14, by w
" 1–12 " 4–13, by x
" 2–11 " 3–14, by y
" 2–11 " 4–13, by z

Table IX shows the changes in these coefficients due to successive phantom transpositions of one or both groups.

The use of this table permits working out readily the degree of balance between the physical circuits when the phantoms are transposed to any given patterns. If there are three equidistant phantom transpositions in one group between the phantom transpositions of the other, there is complete balance for all the inductive relations of the physical circuits. With a few exceptions, there is balance for the physical circuits whenever one phantom has gained three transpositions on the other one, whether this gain be made in one or several transpositions sections of the line. Some patterns give balance of the physical circuits in two sections. The effect of phase displacement prevents depending on the phantom transpositions to balance the physical circuits except when a satisfactory degree of balance is obtained in one section.

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[6] Loc. cit. facing p. 744.

TABLE IX.
EFFECT OF PHANTOM TRANSPOSITIONS ON COEFFICIENTS OF INDUCTION BETWEEN CIRCUITS IN DIFFERENT GROUPS.

Circuits initially in the position										
	Number of Transposition:									
		1	2	3	4	1	2	3	4	
	Number of Element:									
	1	2	3	4	5	1	2	3	4	5
	Group 1–12–2–11 transposed									
	To right					To left				
1–12 and 3–14	w	y	$-w$	$-y$	w	w	$-y$	$-w$	y	w
1–12 and 4–13	x	z	$-x$	$-z$	x	x	$-z$	$-x$	z	x
2–11 and 3–14	y	$-w$	$-y$	w	y	w	w	y	$-w$	$-y$
2–11 and 4–13	z	$-x$	$-z$	x	z	z	x	$-z$	$-x$	z
	Group 3–14–4–13 transposed									
	To right					To left				
1–12 and 3–14	w	x	$-w$	$-x$	w	w	$-x$	$-w$	x	w
1–12 and 4–13	x	$-w$	$-x$	w	x	x	w	$-x$	$-w$	x
2–11 and 3–14	y	z	$-y$	$-z$	y	y	$-z$	$-y$	z	y
2–11 and 4–13	z	$-y$	$-z$	y	z	z	y	$-z$	$-y$	z
	Both groups transposed									
	Same direction					Opposite direction				
1–12 and 3–14	w	z	w	z	w	w	$-z$	w	$-z$	w
1–12 and 4–13	x	$-y$	x	$-y$	x	x	y	x	y	x
2–11 and 3–14	y	$-x$	y	$-x$	y	y	x	y	x	y
2–11 and 4–13	z	w	z	w	z	z	$-w$	z	$-w$	z

For groups with their diagonals in parallel planes, as is the case in all the forms illustrated, x is equal to y, whatever the relative position of the groups, so that simultaneous phantom transpositions of both groups in the same direction balance the x and y values. Referring to Table II and the figures shows that when the sides of the groups are in line, w and z are small compared to x and y. If the diagonals are in line, and in most other cases, w and z are opposite in sign and nearly equal. Hence in any case the simultaneous phantom transpositions leave only a small residual unbalance, equal to $(w + z)/2$ per unit length, between the circuits whose planes are parallel.

For example, let the following groups in Form *A* have the same pattern of phantom transposition:

1-12-2-11 and 3-14-4-13. $w = 22.31$, $x = 102.17$, $y = 102.17$, $z = 22.31$, $(w + z)/2 = 22.31$, *M* between phantoms, -17.86.
1-12-2-11 and 23-34-24-33. $w = -57.54$, $x = 0$, y 0, $z = 44.63$, $(w + z)/2 = -6.46$ *M* between phantoms, 4.77.
1-12-2-11 and 5-16-6-15. $w = 1.55$, $x = 25.03$, $y = 25.03$, $z = 1.55$, $(w + z)/2 = 1.55$, *M* between phantoms, 1.17.
1-12-2-11 and 25-36-26-35. $w = -16.25$, $x = 11.99$, $y = 11.99$. $z = 16.69$, $(w + z)/2 = -0.28$, *M* between phantoms, 0.21.

These figures illustrate the statement previously made that whenever the mutual unbalance between phantoms can be neglected, the same is true of the physical circuits.

Then following table of co-efficients between groups I and IV in Fig. 10 illustrates the use of Table IX.

Transp. pole	.	2	4	6	8	10	12	14
1-12 to 21-32	w	z	$-x$	y	$-w$	$-z$	x	$-y$
1-12 to 22-31	x	$-y$	w	z	$-x$	y	$-w$	$-z$
2-11 to 21-32	y	$-x$	$-z$	$-w$	$-y$	x	z	w
2-11 to 22-31	z	w	y	$-x$	$-z$	$-w$	$-y$	x

The sum of each horizontal line is zero, and inspection will show that since $x = y$, the larger co-efficients, are balanced in each quarter section.

The phantom transpositions with left and right handed rotation resemble the present types 2 and 3 phantom transpositions. By using transposition insulators and brackets, types analogous to 1 and 4 could be introduced, but apparently there would be no advantage in doing so.

g. *Formulas Used.* In Fig. 1, the solid lines are circles for which the radius is:

$$R = \frac{2\,a\,q}{q^2 - 1} \tag{5}$$

and the intercept on the X-axis is

$$x_1 = a\,\frac{q-1}{q+1} \tag{6}$$

where

$$q = \left(\frac{2\,a}{r}\right)^{1-2_{n}} \tag{7}$$

n being the fraction of the flux, or potential difference, to be included within the given curve, and a, half the distance between wires. Curves are drawn for $n = 0.4$, 0.45, 0.5, 0.55, 0.6.

The dotted lines have the equation

$$y^2 = \pm \sqrt{(a^2 - x_1^2)^2 + 4\,a^2\,x^2} - a^2 - x^2 \qquad \textbf{(8)}$$

When x_1 is less than a,

$$x_1^2 = a^2 \left[1 - \left(\frac{a}{2\,r} \right)^{n^{-1}} \right] \qquad \textbf{(9)}$$

When x_1 is greater than a, the sign of the second term within the brackets is reversed. The unit of flux ($n = 1$) is the amount of flux linking only one wire. For $n = 1$, the curve shaped like a Fig. 8 is obtained. Curves are drawn for $n = 0.8$, 1.0, 1.2, 1.4, 1.6.

Mutual Inductances. Physical circuits 1–2 and 3–4

$$M = \log_e \frac{d_{14}^2\,d_{23}^2}{d_{13}^2\,d_{24}^2} \qquad \textbf{(10)}$$

where d_{14} = distance from wire 1 to wire 4
etc. etc.

Phantom 1–2–3–4 and its own side circuit 3–4.

$$M = \frac{1}{2} \log_e \frac{d_{14}^2\,d_{24}^2}{d_{13}^2\,d_{23}^2} \qquad \textbf{(11)}$$

Phantom 1–2–3–4 and circuit 5–6

$$M = \frac{1}{2} \log_e \frac{d_{16}^2\,d_{26}^2\,d_{35}^2\,d_{45}^2}{d_{15}^2\,d_{25}^2\,d_{36}^2\,d_{46}^2} \qquad \textbf{(12)}$$

Phantom 1–2–3–4 and Phantom 5–6–7–8

$$M = \frac{1}{4} \log_e \frac{d_{17}^2\,d_{18}^2\,d_{27}^2\,d_{28}^2\,d_{35}^2\,d_{36}^2\,d_{45}^2\,d_{46}^2}{d_{15}^2\,d_{16}^2\,d_{25}^2\,d_{26}^2\,d_{37}^2\,d_{38}^2\,d_{47}^2\,d_{48}^2} \qquad \textbf{(13)}$$

Self-inductances. Physical circuit,

$$L = 1 + 4 \log_e a/r \qquad \textbf{(14)}$$

in which a is the distance between wires, r the radius of the wires.

Phantom circuit,

$$L = 1/4\,(L_1 + 2\,M + L_2) \qquad \textbf{(15)}$$

in which L_1 and L_2 are the self-inductances of the component circuits 1–3 and 2–4 (or 1–4 and 2–3), and M is the mutual inductance between these circuits, the side circuits being 1–2 and 3–4.

The above formulas give mutual and self-inductances in c.g.s. units per centimeter length. For microhenries per kilometer, multiply by 100.

Capacitances. Physical circuit,

$$C = \frac{1}{4 \log_e a/r} \tag{16}$$

Phantom, standard form, horizontal type,

$$C = \frac{A' + B'}{A\,B' + B\,A'} \tag{17}$$

where $A = \log_e a/r,\qquad B = \log_e 2,$
$A' = \log_e a/r - \log_e 2,\qquad B' = \log_e a/r + \log_e 3/2$

Phantom, proposed form, non-distorted,

$$C = \frac{1}{2 \log_e a/r - \log_e \sqrt{2}} \tag{18}$$

These formulas give capacitances in e.s.u. per cm. length.

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(*Subject to final revision for the Transactions.*)

THEORY OF THE TRANSIENT OSCILLATIONS OF ELECTRICAL NETWORKS AND TRANSMISSION SYSTEMS

BY JOHN R. CARSON

Abstract of Paper

The purpose of this research was to make a broad theoretical study of transient phenomena with a view to developing methods of calculation directly applicable to engineering problems. The investigation starts with the problem of formulating the current in an electrical network or transmission system in response to a suddenly applied e.m.f. of arbitrary form. A simple formula is derived which expresses this current in terms of two independent functions: one, the applied e.m.f. expressed as a time function, and the other a characteristic function of the constants and connections of the system, this latter being termed the "indicial admittance" of the system. A knowledge of the indicial admittance, therefore, completely determines the behavior of the system to all types of applied voltages including both transient and steady states. A systematic investigation of methods for solving and computing the indicial admittance follows, in the course of which original solutions for transmission and artificial lines are derived and a new method involving integral equations is developed. This latter is particularly well adapted to handle the difficult problem of taking into account the effects of terminal impedances in transmission systems.

Introduction and Statement of Problem

WHEN an electromotive force is suddenly applied to an electrical network or system the current flowing in each and every part of the system is, at every instant of time, a determinate function of the form of the applied e. m. f. and of the connections and constants of the system. If the applied voltage is periodic (including, as a limiting case, the uniform steady voltage of zero periodicity) the system ultimately executes periodic oscillations of the same frequency as that of the applied voltage. These "steady-state" or periodic oscillations are the subject of the theory of alternating currents which takes up such a large part of the literature of electrical engineering. A more or less appreciable time after the application of the voltage elapses, however, before the proximate steady state is arrived at, and the oscillations which the system executes in this interval have been roughly termed "transient oscillations," this term implying, of course, that this "unsteady" state dies away or rather merges into the final steady state.

From a practical standpoint a knowledge of the steady state phenomena is sufficient in the great majority of problems. Theoretically, however, the so-called "transients" are of fundamental importance, and in certain problems, notably those of long distance telephony and telegraphy, the steady state theory is quite inadequate and the investigation of transient conditions becomes a matter of practical importance as well. The present paper is the outgrowth of an investigation, undertaken in connection with the writer's work in the Engineering Department of the American Telephone and Telegraph Company, of speech-excited transients in telephone systems, with particular reference to long, loaded cable circuits.

Stated in its broadest terms, our problem is to formulate, as a function of time, the current which flows in any part of an electrical system in response to a voltage of any specified form or type which is suddenly impressed on the system. After the development of the general theory and formulas, a considerable and by no means the least important part of the paper is devoted to deriving fundamental solutions, which admit of easy interpretation and computation, for the transmission line having continuously distributed inductance, capacity, resistance and leakage and the corresponding artificial line in which these constants are lumped. Formulas **32** to **36** and **52** to **64**, which give the solutions for the current and voltage waves in all the important types of transmission system, are all the original results of the present research with the exception of formulas (**57**) and (**62**) which are the solutions for the current and voltage waves in the non-inductive, leakageless cable, first derived by Kelvin and Heaviside and formula (**53**) for the current wave in the leakageless line, which was independently derived by Heaviside and Poincare.

The investigation naturally falls into five parts:

1. The derivation of a general formula expressing the current as a function of the form of the applied voltage and the connections of the particular system under consideration. It will be shown that the current is simply expressed in terms of two functions, one the applied voltage, considered as a time

function, and the other a characteristic function of the system which is independent of the form of the applied voltage. This characteristic function will be termed the "indicial admittance" of the system, a terminology whose oppositeness will be justified by the physical and mathematical significance of the function. The word "indicial" indicates that the function is really an index of the system, and completely determines the behavior of the system to all types of applied voltages. On the other hand, the word "admittance" indicates that the function is of the nature of an admittance in a generalized sense, and that it has very real physical significance.

2. In practical problems, the applied voltage of the greatest importance is the mono-periodic or sinusoidal. For this particular type of e. m. f. special formulas are derived and a mechanical method of numerical solution is developed and described.

3. In (1) and (2) a knowledge of the "indicial admittance" is implied. A systematic investigation of the possible methods of solving for this function is taken up, and appropriate methods for particular types of systems, notably transmission systems, are developed.

4. The indicial admittance functions for all the important types of transmission systems, including the periodically loaded line are derived, and a large number of graphs of these functions is shown.

5. The appropriate treatment to take care of the effects of terminal apparatus in transmission systems is developed and applied to a number of specific problems.

I. General Theory and Formulas. The mathematical basis of the following investigation is furnished in a paper published by the writer in the *Physical Review* (Sept., 1917, pp. 217). A brief resume of the theory and formulas there developed will now be given as a necessary preliminary to the subsequent investigation; for a more detailed treatment the reader is referred to the original paper.

The current in any part of an electrical system or network is related to the impressed voltage (or voltages) by a set of linear differential equations in the variable t (time). If the applied voltage is taken as $E\,\epsilon^{pt}$, and if the differential operator $\frac{d^n}{d\,t^n}$ is replaced by p^n, the differential equations reduce to a set of simultaneous algebraic equations, and by purely algebraic processes we get the symbolic formula or solution

$$I = \frac{E\ \epsilon^{pt}}{Z\ (p)} \tag{1}$$

In the symbolic formula (**1**), $Z\ (p)$ is the impedance function; it is the ratio of two determinants (or the limit of such a ratio), and the equation $Z\ (p) = 0$, which is of frequent occurrence, will be termed the determinantal equation. If p is taken as a pure imaginary, formula (**1**) is simply the usual complex expression for the steady state current, and the real part of (**1**) the periodic current, corresponding to an impressed voltage of frequency $\frac{p}{2\ \pi}$. At present, however, no restriction is imposed on the operator p, and (**1**) is to be regarded as purely symbolic.

Starting with formula (**1**), the writer showed, in the paper referred to above, that, if the voltage is impressed on the system at time $t = 0$, the resultant current is expressed by the formula:

$$I = E \left[\frac{\epsilon^{pt}}{Z\ (p)} + \Sigma^m \frac{\epsilon^{p_m t}}{(p_m - p)\ Z'\ (p_m)} \right] \tag{2}$$

where p_m is the mth root of $Z\ (p)$, the summation is extended over all the roots of $Z\ (p)$ and

$$Z'\ (p_m) = \left[\frac{d}{d\,p} Z\ (p) \right]_{p\,=\,p_m}$$

In formula (**2**), p is no longer a mere operator and is assigned the value, real, imaginary or complex, which characterizes the impressed voltage. Thus if the impressed voltage is a unit d-c. voltage (zero before, unity after $t = 0$), $E = 1$, $p = 0$, (**2**) and becomes:

$$I = A\ (t) = \frac{1}{Z\ (0)} + \Sigma^m \frac{\epsilon^{p_m t}}{p_m\ Z'\ (p_m)} \tag{3}$$

which is the Heaviside expansion formula.

The function formulated by (**3**) is fundamental to our whole problem and will be defined as follows:

The *indicial admittance* of an electrical network or system is equal to the current, expressed as a time function, which flows in the system in response to a unit d-c. voltage (zero before, unity after $t = 0$) applied to the system at time $t = 0$. It is mathematically defined and formulated by (3) and will be denoted by $A(t)$ with appropriate subscripts. Thus if the applied voltage is inserted in the j^{th} mesh or branch of the network, the current in the k^{th} mesh or branch (assuming a unit d-c. voltage) will be denoted by $A_{jk}(t)$. The indicial admittance $A(t)$ is of the dimensions and character of an admittance in a generalized sense and is subject to the reciprocal relation $A_{jk}(t) = A_{kj}(t)$. When the two subscripts are the same the function may conveniently be referred to as the *driving point indicial admittance*, while when the subscripts are different, it will be termed the *transfer indicial admittance*, thus correlating our conceptions and terminology with those commonly employed in the theory of steady state or periodic phenomena. An important distinction, however, exists between the indicial admittance, as defined above, and the steady state admittance in that the former is a function of time while the latter is a function of frequency.

We shall now show that the "indicial admittance" completely determines the behavior of the system to all types of impressed voltages; in other words, that a knowledge of the indicial admittance alone is all that is required to completely specify the system, and predict its performance under all circumstances. The proof is based on a well known partial expansion which is employed and fully discussed in my paper referred to above. By a slight extension of the theory there developed it may be shown that all the impedance functions with which we are concerned admit of the partial fraction expansion:

$$\frac{1}{Z(p)} = \frac{1}{Z(\infty)} + \Sigma^m \frac{1}{(p - p_m)\, Z'(p_m)} \tag{4}$$

whence:

$$\frac{1}{Z(0)} = \frac{1}{Z(\infty)} - \Sigma^m \frac{1}{p_m\, Z'(p_m)} \tag{5}$$

Comparing (3) and (5) it is at once evident that

$$\frac{1}{Z(\infty)} = A(0)$$

$\frac{1}{Z(\infty)}$, and hence $A(0)$, is usually zero, except when, due to the absence of finite inductance, the current corresponding to $A\ (t)$ has an initial jump to a finite or even infinite value.

Returning now to equation (**2**) and replacing $\frac{1}{Z\ (p)}$ by its value as given by (**4**) we get:

$$I = E \left[\frac{\epsilon^{pt}}{Z\ (\infty)} + \epsilon^{pt} \sum_m \frac{\epsilon^{(p_m - p)t} - 1}{(p_m - p)\ Z'\ (p_m)} \right]$$

which is clearly equal to:

$$I = E \left[\frac{\epsilon^{pt}}{Z\ (\infty)} + \epsilon^{pt} \int_0^t \epsilon^{-p\lambda} \sum_m \frac{\epsilon^{p_m \lambda}}{Z'\ (p_m)}\ d\ \lambda \right] \qquad (\mathbf{6})$$

But by (**3**)

$$\sum_m \frac{\epsilon^{p_m t}}{Z'\ (p_m)} = \frac{d}{d\ t}\ A\ (t) = A'\ (t)$$

$$\frac{1}{Z\ (\infty)} = A\ (0)$$

Substitution of these identities in (**6**) gives

$$I = A\ (0)\ E\ \epsilon^{pt} + \int_0^t E\ \epsilon^{p\ (t-\lambda)}\ A'\ (\lambda)\ d\ \lambda \qquad (\mathbf{7})$$

By obvious transformations (**7**) may also be written in either of the equivalent forms,

$$I = \frac{d}{dt} \int_0^t E\ \epsilon^{p\ (t-\lambda)}\ A\ (\lambda)\ d\ \lambda$$

$$= \frac{d}{dt} \int_0^t E\ \epsilon^{p\lambda}\ A\ (t - \lambda)\ d\ \lambda \qquad (\mathbf{8})$$

which are sometimes more convenient to handle than is (**7**).

If the impressed voltage is the mono-periodic or sinusoidal function

$$E \sin\ (p\ t + \theta)$$

it is easy to show (by writing the sine function is its complex exponential form) that (**7**) becomes,

$$I = A\ (0)\ E \sin\ (p\,t + \theta) + \int_0^t E \sin\ (\,p\ (t - \lambda) + \theta\,) \cdot A'\ (\lambda)\ d\ \lambda \tag{9}$$

More generally if the impressed voltage $f\ (t)$ is not a pure sinusoid but is expressible (for $t > 0$) as a Fourier series:

$$f\ (t) \qquad = \Sigma^k\ a_k\ \ \sin\ (p_k\,t + \theta_k\ )$$

$$f\ (t - \lambda) = \Sigma^k\ a_k\ \ \sin\ (\ p_k\ (t - \lambda) + \theta_k\ )$$

equation (**9**) becomes, since the relations are linear,

$$I = A\ (0)\,f\ (t) + \int_0^t f\ (t - \lambda) \cdot A'\ (\lambda) \cdot d\ \lambda \tag{10}$$

while (**8**) becomes

$$I = \frac{d}{dt} \int_0^t f\ (t - \lambda) \cdot A\ (\lambda)\ d\lambda$$

$$= \frac{d}{dt} \int_0^t f\ (\lambda)\ A\ (t - \lambda)\ d\lambda \tag{11}$$

Equations (**11**) are the fundamental formulas which mathematically relate the current to the type of applied voltage and the connections of the system, and constitute the solution of the first part of our problem. The most important deductions from these formulas are expressed in the following theorems:

1. *The indicial admittance of an electrical network or system completely determines, within a single quadrature, the behavior of the system to all types of applied voltages.* As a corollary, a knowledge of the indicial admittance is the sole information necessary to predict completely the performance and characteristics of the system.

2. *The applied voltage and the indicial admittance are similarly and coequally related to the instantaneous current flowing in the system.* As a corollary, the form of the current may be modified either by changing the connections and constants of the system (and thus modifying $A\ (t)$) or by modifying the form of the applied voltage.

Since the applied voltage may be discontinuous formulas (**11**) not only determine the building up of the current in response to an applied voltage, but also its subsidence to equilibrium when an applied voltage is removed and the system is left to itself. In brief, *formulas* (**11**) *reduce the whole problem to a determination of the indicial admittances of the system,* a problem which forms the subject matter of succeeding sections of this paper.

The type of applied voltage of the greatest practical importance is the mono-periodic, or sinusoidal. In this case denoting the voltage applied at time $t = 0$, by $E \sin (p t + \theta)$, (**9**) is the appropriate formula. This may be written:

$$\begin{aligned} I = {} & A(0)\, E \sin (p t + \theta) \\ & + E \sin (p t + \theta) \int_0^t \cos p \lambda \cdot A'(\lambda)\, d\lambda \\ & - E \cos (p t + \theta) \int_0^t \sin p \lambda\, A'(\lambda)\, d\lambda \qquad (\mathbf{12}) \end{aligned}$$

which is the formula most convenient in practice. Another formulation which is sometimes preferable is derivable from the first of (**11**)

$$\begin{aligned} I = {} & E \sin \theta\, A(t) \\ & + E p \cdot \cos (p t + \theta) \int_0^t \cos p \lambda \cdot A(\lambda)\, d\lambda \\ & + E p \sin (p t + \theta) \int_0^t \sin p \lambda \cdot A(\lambda)\, d\lambda \qquad (\mathbf{12a}) \end{aligned}$$

Except in rare cases, however, formula (**12**) is preferable and further consideration will be limited to it. From formula (**12**) the final *steady state* current is given by

$$\begin{aligned} & A(0)\, E \sin (p t + \theta) \\ & + E \sin (p t + \theta) \int_0^\infty \cos p \lambda\, A'(\lambda)\, d\lambda \\ & - E \cos (p t + \theta) \int_0^\infty \sin p \lambda\, A'(\lambda)\, d\lambda \qquad (\mathbf{13}) \end{aligned}$$

While the transient distortion (*i. e.*, the difference between the actual and the steady state current) is given by

$$- E \sin (p t + \theta) \int_t^\infty \cos p \lambda A' (\lambda) \, d \lambda$$

$$+ E \cos (p t + \theta) \int_t^\infty \sin p \lambda A' (\lambda) \, d \lambda \qquad \textbf{(14)}$$

The resolution of the total current into two terms, first the steady state current as given by (**13**), and second the transient distortion, as formulated by (**14**), is often of considerable practical advantage. In fact in many practical problems we are primarily concerned with the character and duration of the transient distortion. It should be observed that the "transient distortion" is formally defined by (**14**); it is the difference between the actual total current and the final steady state current.

Formula (**13**) gives the steady state current; this, of course, is derivable by other and far simpler methods so that (**13**) would, in practise, never be used to evaluate the steady state current. However, when equated with the usual steady state formulas, it furnishes an excellent check on the correctness of the theory and formulas, and also a means of evaluating some very complicated infinite integrals, the latter property being of very considerable mathematical interest.

Formula (**13**) also enables us to express the indicial admittance of the system in terms of its steady state admittance as follows. If the applied voltage is $E \sin (p t + \theta)$ and if

$$\frac{1}{Z (ip)} = \alpha (p) + i \beta (p)$$

the expression for the steady state current is by the usual methods

$$I = \alpha (p) . \sin (p t + \theta) + \beta (p) \cdot \cos (p t + \theta)$$

But this is equivalent to (**13**); hence equating the sine and cosine terms,

$$\alpha (p) = A (0) + \int_0^\infty \cos p \lambda A' (\lambda) \, d \lambda$$

$$\beta (p) = - \int_0^\infty \sin p \lambda A' (\lambda) \, d \lambda$$

$\alpha(p)$ and $\beta(p)$ are, of course, the real and imaginary components of the steady state admittances. The first of these equations can be solved giving

$$A(t) = A(0) + \frac{2}{\pi} \int_0^\infty \left(\alpha(p) - A(0) \right) \frac{\sin(tp)}{p} \, dp$$

A very simple example must suffice for the present to illustrate the foregoing theory. Let the system consist of an inductance L in series with a resistance R. Then, by the expansion theorem,

$$A(t) = \frac{1}{R} \left(1 - \epsilon^{-\frac{R}{L} t} \right)$$

$$A'(t) = \frac{1}{L} \epsilon^{-\frac{R}{L} t}$$

Substituting in (**12**), the current is given by

$$I = \frac{E}{L} \sin(pt + \theta) \int_0^t \epsilon^{-\frac{R}{L} \lambda} \cos p\lambda \, d\lambda$$

$$- \frac{E}{L} \cos(pt + \theta) \cdot \int_0^t \epsilon^{-\frac{R}{L} \lambda} \sin p\lambda \, d\lambda$$

which integrates to

$$I = \frac{E}{(pL)^2 + R^2} \left\{ R \sin(pt + \theta) - pL \cos(pt + \theta) \right\}$$

$$+ \frac{E \epsilon^{-\frac{R}{L} t}}{(pL)^2 + R^2} \left\{ pL \cos\theta - R \sin\theta \right\}$$

Here the first term is the steady state and the second term the transient distortion which is exponentially damped, so that the two components—steady state and transient distortion—are automatically separated by the process of integration.

Still limiting our consideration to sinusoidal voltages, the reader may have remarked that we can get the formal solution for the current directly from (**2**) by making p a pure imaginary and thus dispense with the definite integrals of formula (**12**) altogether. When the number of degrees of freedom of the system is small, and when the roots of the determinantal equation $Z(p) = 0$ are easily located, the direct evaluation of formula (2) is indicated; in the great majority of problems, however, we shall find that the employment of the definite integral formula (**12**) effects a great saving of labor, and that, in fact, the solution obtained directly from (**2**) does not admit, practically speaking, of either interpretation or computation. Without going into details, the chief reasons for this are briefly as follows:

1. The direct evaluation of the current from formula (**2**) requires that the indicial admittance be expressed as a sum of characteristic oscillations or vibrations, a form of solution which is not only usually to be avoided for practical reasons but which in a great many problems cannot be obtained.

2. *The definite integrals of formula* (**12**) *admit of mechanical integration when the indicial admittance is known.* On this fact rests the practical, as distinguished from the purely theoretical, value of the formula.

In order to explain the mechanical evaluation or integration of the integrals appearing in (**12**), we remark that they are of precisely the same form as the harmonic components of a Fourier series, differing therefrom only in that no periodicity on the part of $A\ (t)$ is either assumed or implied and in that the upper limit of integration is variable. The suggestion to employ a harmonic analyser is immediate and obvious, and upon investigation it was found that a Coradi harmonic analyser of the rolling sphere type was adapted to evaluate directly the integral terms of (**12**) when $A\ (t)$ is known.

The analyser is applied to the problem of mechanical integration and operates as follows: Having plotted $A\ (t)$ to a suitable time scale (depending on the frequency $p/2\pi$ which is specified, and the geometrical dimensions of the machine), the curve is traced with the pointer of the analyser, precisely as we trace a curve with an integraph or planimeter. As we trace this curve the recording mechanism of the analyser gives directly the progressive values, corresponding to any particular value of t, of the integrals

$$\int_0^t \cos p\,\lambda\, A'\,(\lambda)\, d\,\lambda$$

$$\int_0^t \sin p\,\lambda\, A'\,(\lambda)\, d\,\lambda$$

the value of p depending on the time scale to which $A(t)$ is plotted. But these are precisely the integrals we require to evaluate formula (**12**), and the analyser therefore furnishes the means for the mechanical solution of our problem in a simple direct manner with a minimum of labor. The analyser employed by the writer has three separate harmonic rollers so that formula (**12**) can be evaluated for three different frequencies simultaneously.

I do not wish to give the impression that the labor of computation is reduced to a negligible quantity, for it is still considerable by reason of the very nature of the problem. This follows from the fact that we require, not a single numerical value of I for a particular value of t, as is the case for steady state conditions, but a complete history of the current, as a function of time, from its start up to its steady state value. What I do claim, however, is that the labor is by no means prohibitive and that mechanical integration as described above, furnishes a thoroughly practicable, if not the only practicable means of numerical solution.*

II. The Determination of the Indicial Admittance $A(t)$

By virtue of formulas (**11**) and (**12**), derived and discussed in the preceding section, our problem is reduced to a determination of the indicial admittance $A(t)$. In other words, our problem is now restricted to the formulation of the current flowing in any part of the electrical system or network in response to a unit d-c. voltage (zero before, unity $t = 0$) applied to the system. To the solution of this problem Heaviside devoted the greater part of the first two volumes of his "Electromagnetic Theory" and no student of this subject can fail to express the greatest admiration for his researches, an acquaintance with which is indeed essential to any investigation of the problem. While new problems have presented themselves, the study of which has resulted in new methods and original solutions, Heaviside was the first to treat the problem comprehensively and to insist on solutions which admitted of physical and numerical interpretation, as distinguished from merely formal mathematical expressions which conceal the real nature of the solution as effectually as do the original differential equations of the problem. Furthermore, his expansion theorem alone is a powerful instrument and forms the basis, not only for the special methods of solution developed in this section but also for the transmission line formulas derived in the succeeding sections:

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*See Note 1 at end of paper.

The formal solution of our problem, the determination of the indicial admittance $A(t)$ is furnished by the expansion theorem (**3**):

$$A(t) = \frac{1}{Z(0)} + \Sigma^m \frac{\epsilon^{p_m t}}{p_m Z'(p_m)}$$

For systems or networks which have a relatively small number of degrees of freedom, and the roots of whose determinantal equation $Z(p) = 0$ admit of evaluation, formula (**3**) furnishes the working or practical as well as the formal solution. In the great majority of problems, however, the expansion theorem, as it stands, is of restricted utility as a working solution for several reasons, the chief of which are that it requires the location of the roots of $Z(p)$ and that it involves a prohibitive amount of labor for computation when the number of degrees of freedom is large. On the basis of the expansion theorem we therefore proceed to develop derived methods of solution.

1. *The Power Series Solution.* The solution for $A(t)$ can always be written down in the form of a power series in the variable t (time) without evaluating the roots of the determinantal equation $Z(p) = 0$, provided the function $\frac{1}{Z(p)}$ admits of asymptotic expansion* in the variable p. To prove this theorem and derive the power series solution we proceed as follows:

Return to formula (**3**) and expand the exponential functions in the usual power series. Since this expansion is absolutely convergent, the resultant expansion is absolutely convergent. Making use of the relation (**5**), formula (**3**) then becomes,

$$A(t) = \frac{1}{Z(\infty)} + \frac{t}{1!}\Sigma\frac{1}{Z'(p_m)} + \frac{t^2}{2!}\Sigma\frac{p_m}{Z'(p_m)}$$
$$+ \ldots + \frac{t^n}{n!}\Sigma\frac{p_m{}^{n-1}}{Z'(p_m)} + \ldots$$

Now take equation (**4**) and write it as

$$\frac{1}{Z(p)} = \frac{1}{Z(\infty)} + \frac{1}{p}\Sigma\frac{1}{Z'(p_m)}\left(1 - \frac{p_m}{p}\right)^{-1}$$

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*See Note 2.

Expanding the second factor of the summation by the binomial theorem, and arranging in inverse powers of p, we get,

$$\frac{1}{Z\ (p)} = \frac{1}{Z\ (\infty)} + \frac{1}{p} \Sigma \frac{1}{Z'\ (p_m)} + \frac{1}{p^2} \Sigma \frac{p_m}{Z'\ (p_m)}$$

$$+ \ldots\ldots + \frac{1}{p'} \Sigma \frac{p_m{}^{n-1}}{Z'\ (p_m)} + \ldots\ldots$$

Comparing these two expansions we see at once that the coefficient of $\frac{t^n}{n\,!}$ in the former is identical with the coefficient of $\frac{1}{p^n}$ in the latter. Furthermore, the latter is nothing more than the asymptotic expansion of $\frac{1}{Z\ (p)}$. We therefore arrive at the following rule:

Expand the function $\frac{1}{Z\ (p)}$ *asymptotically in the form*

$$\frac{1}{Z\ (p)} = \overset{\infty}{\underset{0}{\Sigma}}{}^k\, \frac{a_k}{p^k}$$

Then the indicial admittance is given by

$$A\ (t) = \overset{\infty}{\underset{0}{\Sigma}}{}^k\, a_k \frac{t^k}{k\,!}$$

which is gotten from the asymptotic expansion by replacing $\frac{1}{p^n}$ *by* $\frac{t^n}{n\,!}$.

Those familiar with Heaviside's Electromagnetic Theory Vol. II, will recognize in the foregoing expansion the equivalent of his operational solution. Heaviside himself refrained from giving any justification of the solution beyond the pragmatic one that "it works," and so far as I am aware, the above furnishes the first formal proof of its correctness.

As regards the practical value of the power series expansion as a working solution, its utility is rather restricted (except when the expansion can be identified with known functions) by reason of the slow convergence of the series. A second disadvantage lies in the fact that the asymptotic expansions are usually difficult to obtain and of complicated form. Finally, it should be remarked that while $\frac{1}{Z\,(p)}$ always admits of asymptotic expansion for networks having a finite number of degrees of freedom, the asymptotic expansion of $\frac{1}{Z\,(p)}$ for transmission lines, where the number of degrees of freedom is infinite and trancendental functions are involved, is impossible. The method is, however, of very great mathematical interest, and is useful in computing $A\ (t)$ for small values of t.

We cannot at present take up the more developed series solutions of Heaviside where fractional powers of t appear. These solutions are of great methematical interest and will be referred to later in connection with the treatment of transmission line problems. It may be remarked, however, in passing, that their chief application is in connection with the non-inductive cable which is of minor practical importance and whose solution is otherwise derived in Section IV.

2. *The Solution from Fourier's Integral.** It is always possible to express the current as a Fourier integral of the following form:

$$I = \frac{1}{2\,\pi\,i} \int_{-\infty}^{\infty} f\,(\lambda)\,d\,\lambda \int_{-\infty\,i}^{\infty\,i} \frac{\epsilon^{p(t-\lambda)}}{Z(p)}\,d\,p$$

where $f\ (t)$ is the impressed voltage and $Z\ (p)$ is the impedance function. It can be shown that this double integral is capable of reduction to the expansion theorem solution or the power series solution (for either integral or fractional powers of t), and it thus furnishes a check on these fundamental formulas.

3. *The Synthetic Method.* In many problems which do not admit of a working solution by direct methods of attack, the solution can be built up from the solutions for the component parts of the system under consideration by a method recently developed and employed by the writer. A notable example of the type of problem to which the method is applicable is furnished by the transmission line. Here, as we shall show later, the solution can be gotten for a line of any length if the voltage is applied directly to one end of the line and the other

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*See Note 3.

end is short-circuited. When, however, the voltage is applied through terminal apparatus, and the other end is closed through terminal apparatus, or when apparatus is inserted at any point along the line, the solution by direct frontal attack is impossible. The effects of such terminal or intermediate apparatus can be solved for, both formally and numerically, by the synthetic method which promises to be an instrument of value in the solution of practically important problems. Again the system may be a "compound" system or network which is made up of two separate networks, coupled or connected in any specified manner. This method furnishes us a means for determining the indicial admittances of the compound system in terms of the indicial admittances (assumed known) of the component networks, when direct methods are incapable of yielding a solution. A particular problem of this character is the determination of the modifying effects of inserting additional impedance elements in a network.

The method, as the name implies, is synthetic and physical in character, and the formulas are indeed based on physical reasoning rather than on mathematical analysis. From the mathematical standpoint, however, the method is of interest in that it applies the theory of integral equations* to the transient problem.

Briefly stated, the principle underlying the method consists in building up the solution for a network or system from the known solutions for its component parts. We now proceed to a discussion of the theory and a derivation of the formulas.

To make the application as general as possible we shall assume that we have two networks or systems, and we shall further assume that the indicial admittances of each are known. Our problem is to determine the indicial admittances (and hence the complete behavior and characteristics) of the compound network or system which is formed by connecting the two given systems in any specified manner. A sufficiently general manner of connecting the two networks is to open any mesh or branch of one network and any mesh or branch of the other network, and to connect the corresponding open terminals of the two networks, thus forming a compound network. This manner of coupling is illustrated schematically in the accompanying sketches.

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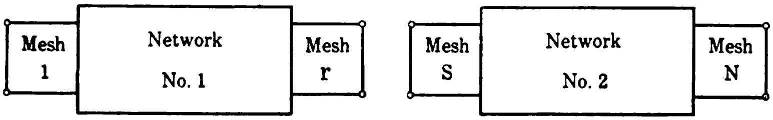
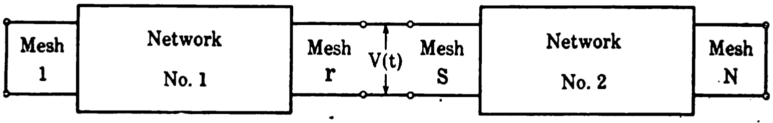
*See Note 4.





To proceed with the theory, let network No. 1 consist of m meshes or branches, numbered from 1 to m, and let network No. 2 consist of n meshes or branches, numbered from I to N. Let the indicial admittances of No. 1 be denoted by $a_{jk}(t)$ (the subscripts depending, of course, on the meshes with which we are concerned) and those of No. 2 by $b_{JK}(t)$. Now to couple these networks open any mesh, say the r^{th} of No. 1, and any mesh, say the S^{th} of No. 2, and connect the open terminals of mesh r to open terminals of mesh S. The two networks are thus connected together through their r^{th} and S^{th} meshes respectively and form a compound system. We require the indicial admittances of the compound system in terms of the known indicial admittances of the two component networks.

To formulate the required admittances, assume, as usual, a unit e.m.f. inserted at time $t = 0$ in any mesh of the compound system, say the 1st mesh of network No. 1; then by definition the current flowing in mesh j of network No. 1 is $A_{1j}(t)$ and the corresponding current flowing in mesh J of network No. 2 is $A_{1J}(t)$.

Now an unknown voltage $V(t)$ exists across the common terminals which connect the two networks; hence the current flowing in any mesh of network No. 1 is the same as that which would flow if the network were isolated and actuated by a unit e.m.f. inserted in mesh 1 and an e.m.f. $-V(t)$ in mesh r. Hence by reference to formula (**11**)

$$A_{1r}(t) = a_{1r}(t) - \frac{d}{dt}\int_0^t V(\lambda)\, a_{rr}(t-\lambda)\, d\lambda \qquad \textbf{(a)}$$

By precisely the same physical reasoning we get

$$A_{1S}(t) = \frac{d}{dt}\int_0^t V(\lambda)\cdot b_{SS}(t-\lambda)\, d\lambda \qquad \textbf{(b)}$$

since network No. 2, regarded as isolated, is subject only to the impressed voltage $V(t)$ in mesh S.

But owing to the connections of the two networks, the currents corresponding to equations (**a**) and (**b**) are necessarily equal, whence:

$$A_{1r}(t) = A_{1S}(t) \qquad \text{, and}$$

$$\frac{d}{dt}\int_0^t V(\lambda)\,[\,a_{rr}(t-\lambda) + b_{SS}(t-\lambda)\,]\;d\lambda = a_{1r}(t) \qquad \textbf{(c)}$$

Now this is an integral equation in the unknown voltage $V(t)$ and is reducible to the canonical form

$$V(t) = f(t) + \int_0^t V(\lambda)\,u(t-\lambda)\,d\lambda \qquad \textbf{(d)}$$

where $f(t)$ and $u(t)$ are known functions.

The formal mathematical solution of this integral equation can be written down, by the method of successive substitutions, in the form of an absolutely convergent series. Furthermore, without solving the integral equations, we can immediately derive the power series solution (in case a power series solution in integral powers of t exists) by repeated differentiations of equation (**d**). When the power series solution involves fractional powers of t, this fact is at once evident from the form of the known functions appearing in (**d**), and the correct series solution can be derived from the integral equation as it stands. Having solved in some such manner for $V(t)$ the required indicial admittances are gotten from equations (**a**) and (**b**) by a single quadrature.

The practical value of this method of solution, as distinguished from its purely theoretical and mathematical interest, lies in the possibility of the numerical integration of the integral equations in cases where the formal and power series solutions are impracticable from the standpoint of interpretation or computation. The numerical integration works out well in practise, it may be made as accurate as we please, and gives the required numerical solution directly and with a minimum of labor. In practise, furthermore, the method is not so complicated as might appear from the sketch of the theory and often various short cuts are suggested by physical considerations. It is also applicable to problems other than that explicitly considered above; for example it yields a relatively easy numerical solution of an important problem in telegraphy, namely, the required form of impressed voltage to produce a prescribed form of arrival curve.

Space forbids further consideration of this method which the writer hopes to treat in greater detail in a future paper, and I must content myself with giving the simplest possible example of the method. Let network No. 1 consist of a resistance R and No. 2 of an inductance L so that the "compound" system consists of a resistance R in series with an inductance L. The indicial admittance of this system is, of course, known to be

$$\frac{1}{R}\left(1-\epsilon^{-\frac{R}{L}t}\right).$$

This solution will now be verified by the method just discussed. We have

$$a(t)=\frac{1}{R}$$

$$b(t)=\frac{1}{L}t$$

Substitution in (c) gives

$$\frac{d}{dt}\int_0^t V(\lambda)\left[\frac{1}{R}+\frac{1}{L}(t-\lambda)\right]d\lambda=\frac{1}{R}$$

Differentiating and rearranging

$$V(t)=1-\frac{R}{L}\cdot\int_0^t V(\lambda)\,d\lambda$$

By the method of successive substitutions the solution of this integral equation is:

$$\begin{aligned}V(t)&=1-\frac{R}{L}\cdot\int_0^t d\lambda+\left(\frac{R}{L}\right)^2\cdot\int_0^t\int_0^\lambda d\lambda\,d\lambda_1\\&\quad-\left(\frac{R}{L}\right)^3\cdot\int_0^t\int_0^\lambda\int_0^\lambda d\lambda\,d\lambda_1\,d\lambda_2+\ldots\\&=1-\left(\frac{R}{L}\right)\frac{t}{1!}+\left(\frac{R}{L}\right)^2\frac{t^2}{2!}\\&\quad-\left(\frac{R}{L}\right)^3\frac{t^3}{3!}+\\&=\epsilon^{-\frac{R}{L}t}\end{aligned}$$

Hence

$$A(t) = \frac{1}{R}(1 - V(t))$$

$$= \frac{1}{R}\left(1 - \epsilon^{-\frac{R}{L}t}\right)$$

which is the correct solution.

4. *Special Methods for the Solution of Transmission Systems.* In treating the problem presented by the transmission system, embracing, on the one hand, the transmission line having continuously distributed constants, and on the other, the artificial line whose constants are lumped or localized, and including as intermediate between these two the periodically loaded cable, we shall derive the basic solutions for the simplest possible configuration, namely when the voltage is applied directly to the line and the distant end is short circuited. It will then be shown that the effect of terminal and intermediate apparatus can be formulated and numerically computed from the basic solution by aid of the synthetic method of treatment just discussed. The solution for the line itself is therefore fundamental.

Now limiting for the present our consideration to the line which is short-circuited at one end, and excited by the direct application of a voltage at the other end, the symbolic formula is readily written down; its general form is well known to be

$$\frac{1}{K} \frac{\cosh \gamma (s - x)}{\sinh (\gamma s)} \cdot \epsilon^{pt}$$

This is the symbolic formula for the current at point x of a line which is short-circuited at $x = s$ and is excited by a voltage applied at $x = 0$. K and γ are functions of the operator p, and the line constants. (If we are dealing with an artificial line s and x are to be interpreted as number of sections instead of distance; the form of function is, however, the same in both cases.)

Now for the smooth line (having continuously distributed constants) and for the artificial line, the expansion theorem solution can be written down without any trouble. As a working or practical solution this is, however, of no utility as it stands, owing to the fact that the number of terms in the summation is infinite for the smooth line (and very large for long artificial lines) and the convergence very slow. Physically this difficulty arises from the fact that the expansion theorem solution formulates the current or indicial admittance, as a sum of characteristic oscillations or vibrations, a formulation which is mathematically correct but physically artificial. In reality the current travels out in the form of a wave which is reflected at the distant end, and which is independent of the distant termination for a definite time. Each one of the modes of characteristic oscillation involves, however, the character of the distant termination. Investigation shows that if we deal with the *infinitely* long line the sum of characteristic oscillations is converted into the direct wave which alone exists in the infinitely long line, and that this wave is expressible in terms of known functions.

To handle the case of the infinitely long line we set up the expansion theorem solution for a line of length s and then let s approach the limit infinity. As s approaches infinity, the summation of the characteristic oscillations is converted into a definite integral, which, for the practically important types of lines considered in succeeding sections, admits of evaluation in terms of known functions.

To now apply the solution for the infinitely long line to the case of the line of finite length we remark that the current, say $\phi_x(t)$, which exists at point x and time t of a line of infinite length with unit d-c. voltage (zero before, unity after $t = 0$) applied at $x = 0$, is the solution of the problem whose symbolic formula or solution is

$$\frac{1}{K} \cdot \epsilon^{-x\gamma}$$

Now, take the formula given above, for the line of finite length s, express the hyperbolic functions in their equivalent exponential form, and expand; we get

$$\frac{1}{K}\epsilon^{-\gamma x} + \Sigma \frac{1}{K}\epsilon^{-\gamma(2ms+x)} + \Sigma \frac{1}{K}\epsilon^{-\gamma(2ms-x)}$$

Now, by definition, $\phi_x(t)$ is the solution for the first term; hence the solution for the term, $1/K\ \epsilon^{-(2ms+x)}$, is

$$\phi_{2ms+x}(t)$$

which is gotten from $\phi_x(t)$ (a function of x and t) by replacing x with $2ms + x$. Hence the solution for the short circuited line of length s is simply

$$A_x(t) = \phi(t) + \Sigma\phi_{2ms+x}(t) + \Sigma\phi_{2ms-x}(t) \qquad (15)$$

The first term in the above is the direct wave (the only wave which would exist if the line were infinitely long) the first summation represents the series of waves reflected from the sending end, and the second summation the series of waves reflected from the other end of the line. The summations are rapidly convergent, and the above furnishes the working solution which we shall employ.

If, now a voltage $V_1(t)$ is applied at $x = 0$, and a voltage $V_2(t)$ at $x = s$, the current $I_x(t)$ at point x is the aid of formula (**11**):

$$\begin{aligned} I_x(t) = {} & \frac{d}{dt}\int_0^t V_1(t-\lambda)\left\{\phi_x(\lambda) + \Sigma_m\, \phi_{2ms+x}(\lambda) + \Sigma_m\, \phi_{2ms-x}(\lambda)\right\} d\lambda \\ & - \frac{d}{dt}\int_0^t V_2(t-\lambda)\left\{\phi_{s-x}(\lambda) + \Sigma_m\, \phi_{(2m+1)s-x}(\lambda) + \phi_{(2m-1)s+x}(\lambda)\right\} d\lambda \end{aligned} \tag{16}$$

This is a formula of fundamental importance to the whole theory of transmission systems. If the line is of great length (large attenuation) and the applied voltages are alternating, the reflected waves are negligible and we have the approximate formula,

$$I_x(t) = \frac{d}{dt}\int_0^t V_1(t-\lambda)\,\phi_x(\lambda)\,d\lambda - \frac{d}{dt}\int_0^t V_2(t-\lambda)\,\phi_{s-x}(\lambda)\,d\lambda$$

The *driving point* indicial admittance of the line is gotten from (**15**) by setting $s = 0$; denoting it by $A_1(t)$ it is

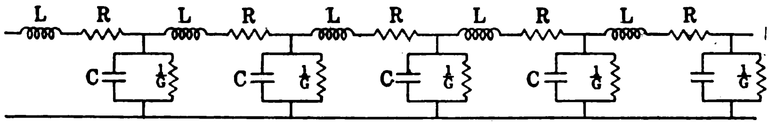
$$A_1(t) = \phi_0(t) + 2\sum_1^\infty {}_m\, \phi_{2ms}(t) \tag{16}$$

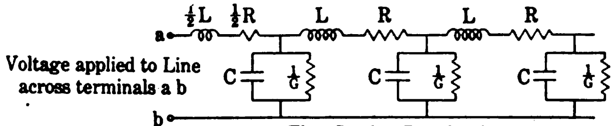
The *transfer* indicial admittance; *i. e.* the current at $x = s$ with line short-circuited at $x = s$, is gotten from (**15**) by setting $x = s$. Denoting this function by $A_2(t)$ it is:

$$A_2(t) = 2\sum_1^\infty {}_m\, \phi_{(2m-1)s}(t) \tag{16a}$$

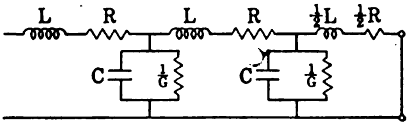
III. Solution for the Artificial Line

The artificial line is a periodic structure of the character shown in the sketch herewith.





First Section Termination



n^{th} Section Termination

Each section of the structure consists of an inductance L and a resistance R in series with the line, and the parallel combination of a capacity C and a leakage conductance G in shunt across the line. The structure which we shall consider is of n sections in length, and the voltage is applied at "mid-series" position, and the nth section is short-circuited at mid-series as shown in the sketches herewith. These terminations are chosen not only because they simplify the analysis somewhat but because they are of practical importance.

A study of the transient properties of the artificial line is important for several reasons:

1. The artificial line is often used as a model of an actual transmission line and it is therefore of importance to determine theoretically the degree of correspondence between the two.
2. The solution for the corresponding transmission line with continuously distributed constants is derivable from the solution for the artificial line by keeping the total inductance, resistance, capacity and leakage constant or finite, and letting the number of sections approach infinity.
3. The artificial line is very closely related, in its properties and performance, to the periodically loaded cable, and its solution is, to a first approximation, a working solution for the loaded cable.

4. The structure is of great importance in its own right and is one form of "wave filter" employed in telephone systems.*

The starting point of the solution is the symbolic formula for the current in the qth section of a line of n sections in length, terminated as shown above; it is

$$-(C_p+G)\cdot\frac{\cos(n-q)\,\Gamma}{\sin(\Gamma)\cdot\sin(n\,\Gamma)}\,\epsilon^{pt} \tag{17}$$

where

$$\begin{aligned} v &= \frac{1}{\sqrt{LC}} \\ \rho &= \frac{R}{2L}+\frac{G}{2C} \\ \sigma &= \frac{R}{2L}-\frac{G}{2C} \end{aligned} \tag{17a}$$

and

$$\cos\Gamma = 1+\frac{1}{2}\,\frac{(p+\rho)^2-\sigma^2}{v^2} \tag{17b}$$

This formula may be deduced in a number of ways; perhaps the simplest is a follows: Considering the qth section, write down the circuital equation for the voltage drop around the closed section; after replacing $\frac{d}{dt}$ by p we get (denoting the circuital currents in the $(q-1)st$, qth and $(q+1)st$ sections by I_{q-1}, I_q and I_{q+1} respectively);

$$I_q\left(Lp+R+\frac{2}{Cp+G}\right)-\frac{1}{Cp+G}\,I_{q-1} - \frac{1}{Cp+G}\cdot I_{q+1}=0$$

or

$$I_q\left(\frac{(p+\rho)^2-\sigma^2}{v^2}+2\right)-I_{q-1}-I_{q+1}=0 \tag{18}$$

Equation (**18**) is a difference equation relating the currents in the three adjacent sections; in accordance, therefore, with usual methods we assume a solution of the form

$$I_q = A\,\epsilon^{iq\Gamma}+B\,\epsilon^{-iq\Gamma} \tag{19}$$

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*See Note 5.

where A and B are arbitrary constants and $i\ \Gamma$ is the exponential propagation factor which is to be determined. Substitution of (**21**) in (**20**) gives after simplification:

$$\left(A\ \epsilon^{iq\Gamma} + B\ \epsilon^{-iq\Gamma}\right) \cdot$$

$$\cdot \left(1 + \frac{1}{2}\left(\frac{(p+\rho)^2 - \sigma^2}{v^2}\right) - \frac{\epsilon^{i\Gamma} + \epsilon^{-i\Gamma}}{2}\right) = 0$$

Clearly this equation is satisfied and furthermore leaves two arbitrary constants A and B at our disposal to satisfy any specified terminal conditions if we set

$$\frac{\epsilon^{i\Gamma} + \epsilon^{-i\Gamma}}{2} = \cos \Gamma = 1 + \frac{1}{2}\ \frac{(p+\rho)^2 - \sigma^2}{v^2}$$

which agrees with (**17b**)

If A and B are now determined in accordance with the terminal conditions illustrated above we get, without any trouble, the symbolic formula (**17**) for the current in the qth section of the structure.

Assuming now a unit d-c. voltage applied to the line at time $t = 0$, the current in the qth section is by definition the indicial admittance of the line and will be denoted by $A_q\ (t)$, the double subscript being omitted for convenience; $A_q\ (t)$ is formulated by applying the expansion theorem to the symbolic formula (**17**) with the result that we get without any trouble

$$\begin{aligned} A_q\ (t) = & - \sum \frac{C\ p_m \cos\ (q\ \Gamma_m)}{n \cdot p_m \cdot \left(\dfrac{d\ \Gamma_m}{d\ p_m}\right) \sin\ \Gamma_m}\ \epsilon^{p_m t} \\ & - \frac{G}{C} \sum \frac{C \cdot \cos\ (q\ \Gamma_m)}{n \cdot p_m \cdot \left(\dfrac{d\ \Gamma_m}{d\ p_m}\right) \sin\ \Gamma_m}\ \epsilon^{p_m t} \qquad (\mathbf{20}) \\ & + \frac{G}{C} \sum \frac{C \cdot \cos\ (g\ \Gamma_m)}{n \cdot p_m\ \left(\dfrac{d\ \Gamma_m}{d\ p_m}\right) \sin\ \Gamma_m} \end{aligned}$$

In equation (**20**) p_m and Γ_m are determined by the determinantal equation

$$\sin\ (n\ \Gamma) = 0$$

whence

$$\Gamma_m = m\ \pi/n \qquad m = 0, 1, 2, \ldots . n$$

and

$$\frac{(p_m + \rho)^2 - \sigma^2}{2\, v^2} = -\,(1 - \cos \Gamma_m)$$

It will be observed that (**20**) may be written

$$A_q\,(t) = -\sum \frac{C \cdot \cos\,(q\,\Gamma_m)}{n \cdot \sin\,\Gamma_m \cdot \left(\dfrac{d\,\Gamma_m}{d\,p_m}\right)} \cdot \epsilon^{p_m t}$$

$$-\,\frac{G}{C}\int_0^t d\,t_1 \cdot \sum \frac{C \cdot \cos\,(q\,\Gamma_m)}{n \cdot \sin\,\Gamma_m \cdot \left(\dfrac{d\,\Gamma_m}{d\,p_m}\right)} \cdot \epsilon^{p_m t_1} \qquad (\mathbf{21})$$

since the last two terms are, within a constant, the integral of the first term. This effects a great simplification and reduces our problem to a solution of the first summation of (**20**) or (**21**).

After some straightforward simplification and rearrangement we get

$$F\,(t) = -\,C \sum \frac{\cos\,(q\,\Gamma_m)}{n \cdot \sin\,\Gamma_m \cdot \left(\dfrac{d\,\Gamma_m}{d\,p_m}\right)}\,\epsilon^{p_m t}$$

$$= \frac{\sqrt{2}}{\pi}\sqrt{\frac{C}{L}}\,\epsilon^{-\rho t}\sum \frac{\pi}{n}\,\cdot$$

$$\cdot\,\frac{\cos\left(q\,m\,\dfrac{\pi}{n}\right)}{\sqrt{1 - \cos\left(m\,\dfrac{\pi}{n}\right) - \dfrac{\sigma^2}{2\,v^2}}}\,\cdot$$

$$.\sin\left(\sqrt{2}\,v\,t\sqrt{1 - \cos\left(m\,\frac{\pi}{n}\right) - \frac{\sigma^2}{2\,v^2}}\right)$$

Now in accordance with our previously discussed mode of treatment let n approach infinity and set

$$\frac{\pi}{n} = d\,\lambda$$

$$m\,\frac{\pi}{n} = \lambda$$

In the limit the summation passes into the definite integral and we get:

$$F(t) = \frac{\sqrt{2}}{\pi}\sqrt{\frac{C}{L}}\,\epsilon^{-\rho t}\int_0^\pi \frac{\cos(q\,\lambda)}{\sqrt{1-\cos\lambda-\dfrac{\sigma^2}{2\,v^2}}}\,\cdot$$

$$\cdot\sin\left(\sqrt{2}\,v\,t\sqrt{1-\cos\lambda-\frac{\sigma^2}{2\,v^2}}\right)\cdot d\,\lambda$$

If we now write for convenience

$$\begin{aligned}\rho/2\,v &= \eta\\ \sigma/2\,v &= \zeta\\ 2\,v\,t &= p_c\,t = z\end{aligned} \qquad \mathbf{(22)}$$

and observe that

$$1-\cos\lambda = 2\sin^2\left(\frac{\lambda}{2}\right)$$

we get finally, after a suitable change in the variable and limits of integration,

$$F(z) = \sqrt{\frac{C}{L}}\,\epsilon^{-\eta z}\cdot\frac{2}{\pi}\cdot\int_0^{\pi/2}\frac{\cos(2\,q\,\lambda)}{\sqrt{\sin^2\lambda-\zeta^2}}$$

$$\sin(z\cdot\sqrt{\sin^2\lambda-\zeta^2})\cdot d\,\lambda \qquad \mathbf{(23)}$$

and

$$A_q(t) = F(z) + (\eta-\zeta)\int_0^z F(z_1)\cdot d\,z_1 \qquad \mathbf{(24)}$$

where now $A_q(t)$ is equal to the current in the qth section of an *infinitely* long line instead of the line of finite length with which we started. It will be observed that the integral term of (**24**) vanishes if the leakage conductance G is put equal to zero and that within a constant it is merely the progressive integral of the first term. For both the artificial line and the smooth line the effect of leakage is to introduce an integral term of this character. This integral term is readily evaluated by mechanical integration as soon as the first term of the formula is derived.

Returning to equation (**23**) we observe that

$$\int_0^{\pi/2}\frac{\cos(2\,q\,\lambda)}{\sqrt{\sin^2\lambda-\zeta^2}}\sin(z\cdot\sqrt{\sin^2\lambda-\zeta^2})\cdot d\,\lambda =$$

$$\int_0^z d\,z_1\int_0^{\pi/2}\cos\,(2\,q\,\lambda)\cdot\cos\,(z\cdot\sqrt{\sin^2\lambda-\zeta^2})\cdot d\,\lambda$$

whence $$F(z) = \sqrt{\frac{C}{L}}\, \epsilon^{-\eta z} \int_0^z \Phi(z_1) \cdot d\, z_1 \qquad (25)$$

where $$\Phi(z_1) = \frac{2}{\pi} \int_0^{\pi/2} \cos(2\, q\, \lambda) \cdot \cos(z_1 \sqrt{\sin^2 \lambda - \zeta^2}) \cdot d\, \lambda \qquad (26)$$

Our problem is thus reduced to the solution of the definite integral of (**26**)

The key to the solution of this integral is furnished by the known value of the definite integral:

$$\frac{2}{\pi} \int_0^{\pi/2} (\cos(2\, q\, \lambda) \cdot \cos(z \cdot \sin \lambda) \cdot d\, \lambda = J_{2q}(z) \qquad (27)$$

where $J_{2q}(z)$ is the Bessel function* of the first kind of order $2\, q$ and the argument z. To make use of this known function in solving (**26**) we proceed as follows: Expand the second cosine function appearing in (**26**) in the usual power series. We get

$$\Phi(z_1) = \frac{2}{\pi} \int_0^{\pi/2} d\, \lambda \cdot \cos(2\, q\, \lambda) \cdot$$

$$\Sigma_m \, (-1)^m \frac{z_1^{2m}}{(2\, m)\,!} (\sin^2 \lambda - \zeta^2)^m$$

expanding $(\sin^2 \lambda - \zeta^2)^m$ by the binomial theorem and arranging in powers of ζ^2 this becomes:

$$\Phi(z_1) = \frac{2}{\pi} \int_0^{\pi/2} d\, \lambda \cdot \cos(2\, q\, \lambda)$$

$$\left\{ \begin{aligned} & \Sigma (-1)^m \frac{z_1^{2m}}{(2\, m)\,!} \sin^{2m} \lambda \\ & + \frac{\zeta^2}{1\,!} \Sigma (-1)^m (m+1) \frac{z_1^{2m+2}}{(2\, m + 2)\,!} \sin^{2m} \lambda \\ & + \frac{\zeta^4}{2\,!} \Sigma (-1)^m (m+1)(m+2) \frac{z_1^{2m+4}}{(2\, m + 4)\,!} \sin^{2m} \lambda \\ & + \ldots\ldots \end{aligned} \right. \qquad (28)$$

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*See Note 6.

$$= \varphi_0(z_1) + \frac{\zeta^2}{1\,!}\ \varphi_1(z_1) + \frac{\zeta^4}{2\,!}\ \varphi_2(z_1) + \ldots$$

$$+ \frac{\zeta^{2n}}{n\,!}\ \varphi_n(z_1) \qquad (29)$$

where

$$\varphi_n(z_1) = \frac{2}{\pi}\int_0^{\pi/2} d\,\lambda \cdot \cos(2\,q\,\lambda)\,\cdot$$

$$\Sigma^m\,(-1)_m\,(m+1)\ldots(m+n)\,\frac{z_1^{\,2m+2n}}{(2\,m+2\,n)\,!}\,\sin^{2m}\lambda$$

We observe that

$$\varphi_1(z_1) = \frac{z_1}{2}\int_0^{z_1} \varphi_0(z_2)\cdot d\,z_2$$

$$\cdots\cdots\cdots$$

$$\varphi_n(z_1) = \frac{z_1}{2}\int_0^{z^1} \varphi_{n-1}(z_2)\cdot d\,z_2$$

and

$$\varphi_0(z_1) = \frac{2}{\pi}\int_0^{\pi/2} \cos(2\,q\,\lambda)\,.\,\cos(z_1\,.\,\sin\lambda)\,.\,d\,\lambda$$

$$= J_{2q}(z_1)$$

Hence (**28**) may be written:

$$\begin{aligned}\Phi(z_1) = {} & \varphi_0(z_1) \\ & + \frac{\zeta^2}{1\,!}\cdot\frac{z_1}{2}\int_0^{z_1}\varphi_0(z_2)\,.\,d\,z_2 \\ & + \frac{\zeta^4}{2\,!}\cdot\frac{z_1}{2}\int_0^{z_1}\frac{z_2}{2}\,d\,z_2\int_0^{z_2}\varphi_0(z_3)\,.\,d\,z_3 \\ & + \frac{\zeta^6}{3\,!}\cdot\frac{z_1}{2}\int_0^{z_1}\frac{z_2}{2}\,d\,z_2\,.\int_0^{z_2}\frac{z_3}{2}\,d\,z_3\,. \\ & \qquad \int_0^{z_3}\varphi_0(z_4)\cdot d\,z_4 + \ldots\ldots \qquad (30)\end{aligned}$$

Reversing the order of the multiple integrals appearing in (**30**) we get, after repeated integration and simplification, as the expression for $F(z)$ of equation (**25**)

$$F(z) = \sqrt{\frac{C}{L}}\,\epsilon^{-\eta z} \int_0^z d\,z_1 \cdot J_{2q}(z_1) \cdot \left\{ \begin{array}{l} 1 + \dfrac{\zeta^2 (z^2 - z_1^2)}{2^2} \\ + \dfrac{\zeta^4 (z^2 - z_1^2)^2}{2^2 \cdot 4^2} \\ + \dfrac{\zeta^6 (z^2 - z_1^2)}{2^2 \cdot 4^2 \cdot 6^2} \\ + \ldots\ldots \end{array} \right. \tag{31}$$

The series appearing in the above is the expansion of the known function $I_0 (\zeta \sqrt{z^2 - z_1^2})$ which is the Bessel function of order zero and pure imaginary argument $i\,\zeta \sqrt{z^2 - z_1^2}$ (the function itself is entirely real since even powers alone are present). Hence,

$$F(z) = \sqrt{\frac{C}{L}} \cdot \epsilon^{-\eta z} \int_0^z J_{2q}(z_1) \cdot I_0 (\zeta \sqrt{z^2 - z_1^2}) \cdot d\,z_1$$

and finally, by reference to (**24**), the final solution for $A_q(t)$ is

$$\begin{aligned} A_q(t) = {} & \sqrt{\frac{C}{L}}\,\epsilon^{-\eta z} \int_0^z J_{2q}(z_1) \cdot I_0 (\zeta \sqrt{z^2 - z_1^2}) \cdot d\,z_1 \\ & + (\eta - \zeta) \cdot \int_0^z d\,z_1 \cdot \sqrt{\frac{C}{L}} \cdot \epsilon^{-\eta z_1} \cdot \\ & \int_0^{z_1} J_{2q}(z_2) \cdot I_0 (\zeta \sqrt{z_1^2 - z_2^2}) \cdot d\,z_2 \end{aligned} \tag{32}$$

This is the complete solution for the current in the qth section of an artificial line of infinite length when a unit voltage is applied to the line at time $t = 0$. The second term of (**32**) is merely the integral of the first term multiplied by $(\eta - \zeta)$, and for that reason offers no difficulties in the way of computation. The first term is expressed in terms of Bessel functions whose properties are known and which can be computed. Plots of $A_q(t)$ from equation (**32**) are shown later in this paper when a discussion of the formulas and their physical significance is taken up.

Formula (**32**) is quite general in that all four line constants (*R. L. C. G.*) are finite and unrestricted in value. Certain particular cases corresponding to particular values of or relations among the line constants are of interest and importance.

1. If the leakage conductance $G = 0$, then, by reference to formulas (**17**) and (**22**), $\eta = \zeta$ and (**32**) reduces to

$$A_q(t) = \sqrt{\frac{C}{L}}\, \epsilon^{-\eta z} \int_0^z J_{2q}(z_1) \cdot I_0\left(\zeta \sqrt{z^2 - z_1^2}\right) \cdot d\, z_1 \tag{33}$$

which is the solution for the *leakageless line* $(G = 0)$

2. If $\dfrac{R}{L} = \dfrac{G}{C}$, $\zeta = 0$, (32) reduces to

$$A_q(t) = \sqrt{\frac{C}{L}} \int_0^z \epsilon^{-\eta z_1} \cdot J_{2q}(z_1) \cdot d\, z_1 \tag{34}$$

which is the solution for the *quasi-distortionless line.* This name is, of course, suggested and justified by the fact that the corresponding smooth line (constants continuously distributed), when so proportioned that $\dfrac{R}{L} = \dfrac{G}{C}$, is exactly distortionless. We shall see later that the quasi-distortionless line, while not strictly distortionless, is characterized by a minimum of distorting action.

(3) If the line is non-dissipative $R = G = 0$, and (**32**) reduces to:

$$A_q(t) = \sqrt{\frac{C}{L}} \int_0^z J_{2q}(z_1) \cdot d\, z_1 \tag{35}$$

which is the solution for the *non-dissipative* artificial line made up of pure inductance and capacity only. This solution applies also to the non-dissipative loaded cable*

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*See Note 7.

(4) If $L = G = 0$, the solution reduces to:

$$A_q(t) = \frac{2}{R} \epsilon^{-\frac{2t}{RC}} \cdot I_q\left(\frac{2t}{RC}\right) \tag{36}$$

which is the solution for the *artificial cable.* $I_q\left(\frac{2t}{RC}\right)$ is the Bessels function of order q and pure imaginary argument $\frac{2t}{RC}$. This solution is derivable from (**33**) by letting L approach zero as a limit; as a matter of fact, however, it was derived directly from the expansion theorem solution. The detailed solution is omitted, however, as involving nothing of special interest.

Before entering into a discussion of these formulas and an exposition of their nature and properties we shall first take up the problem of the smooth (continuously loaded) line and derive the solutions for both current and voltage.

IV. Solution for thc Smooth or Continuously Loaded Line

The artificial line whose solution was derived in the preceding section becomes, in the limit, the corresponding smooth or continuously loaded line, if we keep the total value of the line constants finite and constant and let the number of sections approach infinity as a limit. Hence the solution for the smooth line is derivable by purely mathematical processes from the solution given by formula (**32**) for the artificial line. In this section we shall, however, derive the solution directly by aid of the expansion theorem. We shall find that the process of evaluation is precisely analagous, step by step, to that employed in the preceding section.

The symbolic formula for the current I_x at point x of a line of length s, short-circuited at $x = s$, is well known to be

$$I_x = \sqrt{\frac{Cp + G}{Lp + R}} \cdot \frac{\cosh \gamma (s - x)}{\sinh (\gamma s)} \cdot \epsilon^{pt}$$

$$= (Cp + G) \cdot \frac{\cosh \gamma (s - x)}{\gamma \cdot \sinh (\gamma s)} \epsilon^{pt} \tag{37}$$

where R, L, C, and G are the values per unit length of the continuously distributed line constants and

$$\gamma = \sqrt{\{ (Lp + R) (Cp + G) \}}$$

we write

$$\frac{1}{\sqrt{LC}} = v$$

$$\frac{R}{2L} + \frac{G}{2C} = \rho \qquad (38)$$

$$\frac{R}{2L} - \frac{G}{2C} = \sigma$$

whence

$$\frac{G}{C} = \rho - \sigma$$

$$\gamma = \frac{1}{v} \sqrt{(p+\rho)^2 - \sigma^2} \qquad (39)$$

Writing down the expansion theorem solution of (**36**) in accordance with formula (**3**) we get, after some easy simplifications,

$$A_x(t) = C \sum \frac{\cosh(\gamma_m x)}{s \cdot \gamma_m \cdot \left(\frac{d\,\gamma_m}{d\,p_m}\right)} \cdot \epsilon^{p_m t}$$

$$+ (\rho - \sigma) \int_0^t dt_1 \cdot C \sum \frac{\cosh(\gamma_m x)}{s \cdot \gamma_m \cdot \left(\frac{d\,\gamma_m}{d\,p_m}\right)} \epsilon^{p_m t_1} \qquad (40)$$

$A_x(t)$ is, of course, the value of the current at point x and time t when a unit d-c. voltage is applied to the line at $x = 0$ and $t = 0$. We observe that the second term of (**40**) (which vanishes with the leakage), is merely the progressive integral of the first term, so that our problem is to evaluate the expansion formulated by the first term. p_m and γ_m are given by the determinantal equation

$$\sinh(\gamma s) = 0$$

$$\gamma_m = i m \frac{\pi}{s} \qquad m = 0, 1, 2, \ldots \infty$$

$$p_m = -\rho \pm i v \sqrt{\left(m \frac{\pi}{s}\right)^2 - \frac{\sigma^2}{v^2}}$$

For convenience we write

$$\begin{aligned} v\,t &= y \\ \rho/v &= a \\ \sigma/v &= b \end{aligned} \tag{41}$$

and let the length of the line s approach infinity. By processes identical with those developed in the preceding section, the summations in (**40**) are thereby converted into definite integrals and we get without difficulty:

$$\begin{aligned} A_x(t) = {} & \sqrt{\frac{C}{L}}\,\epsilon^{-ay}\cdot\frac{2}{\pi}\int_0^\infty \frac{\cos(x\lambda)\cdot\sin\left(y\sqrt{\lambda^2-b^2}\right)}{\sqrt{\lambda^2-b^2}}\,d\lambda \\ & + (a-b)\int_0^y d\,y_1\cdot\sqrt{\frac{C}{L}}\,\epsilon^{-ay_1}\cdot\frac{2}{\pi} \\ & \int_0^\infty \frac{\cos(x\lambda)\cdot\sin\left(y_1\sqrt{\lambda^2-b^2}\right)}{\sqrt{\lambda^2-b^2}}\,d\lambda \end{aligned} \tag{42}$$

where now $A_x(t)$ is equal to the current at point x and time t of the *infinitely long* line. Observe that the second term is the progressive integral of the first.

We set

$$F(y) = \sqrt{\frac{C}{L}}\,\epsilon^{-ay}\cdot\frac{2}{\pi}\int_0^\infty \frac{\cos(x\lambda)\cdot\sin\left(y\sqrt{\lambda^2-b^2}\right)}{\sqrt{\lambda^2-b^2}}\,d\lambda \tag{43}$$

whence

$$A_x(t) = F(y) + (a-b)\int_0^y F(y_1)\cdot d\,y_1 \tag{44}$$

and proceed with the evaluation of infinite integral factor of $F(y)$. We observe that

$$F(y) = \sqrt{\frac{C}{L}}\,\epsilon^{-ay}\int_0^y \Phi(y_1)\cdot d\,y_1 \tag{45}$$

where

$$\Phi(y_1) = \frac{2}{\pi}\int_0^\infty \cos(x\,\lambda)\cdot\cos\left(y_1\sqrt{\lambda^2-b^2}\right)\cdot d\,\lambda \qquad (46)$$

The key to the solution of this infinite integral is furnished by the known value of the infinite integral

$$\frac{2}{\pi}\int_0^\infty \frac{\sin(y\,\lambda)}{\lambda}\,d\,\lambda$$

which is a discontinuous function of value -1 for $y < o$ and $+1$ for $y > o$.

Returning to (46) expand the second cosine function in the usual power series, and precisely as in the preceding section, subsequently expand $(\lambda^2 - b^2)^m$ by the binomial theorem. We get, after arranging in powers of b,

$$\Phi(y_1) = \frac{2}{\pi}\int_0^\infty d\,\lambda\cdot\cos(x\,\lambda)\left\{\begin{aligned} &\Sigma(-1)^m\frac{y_1^{2m}\,\lambda^{2m}}{(2\,m)\,!} \\ &+\frac{b^2}{1\,!}\,\Sigma(-1)^m\frac{y_1^{2m+2}}{(2\,m+2)\,!}(m+1)\cdot\lambda^{2m} \\ &+\frac{b^4}{2\,!}\,\Sigma(-1)^m\frac{y_1^{2m+4}}{(2\,m+4)\,!}(m+1)\,(m+2)\,\lambda^{2m} \\ &+\ldots \end{aligned}\right. \qquad (47)$$

which corresponds exactly with formula (28) of the preceding section. By analysis precisely the same as that employed in deriving (30), equation (47) is reducible to the form,

$$\begin{aligned} \Phi(y_1) = {}& \varphi(y_1) \\ &+\frac{b^2}{1\,!}\cdot\frac{y_1}{2}\int_0^{y_1}\varphi(y_2)\cdot d\,y_2 \\ &+\frac{b^4}{2\,!}\cdot\frac{y_1}{2}\int_0^{y_1}\frac{y_2}{2}\,d\,y_2\int_0^{y_2}\varphi(y_3)\cdot d\,y_3 \\ &+\frac{b^6}{3\,!}\cdot\frac{y_1}{2}\int_0^{y_1}\frac{y_2}{2}\,d\,y_2\cdot\int_0^{y_2}\frac{y_3}{2}\,d\,y_3\int_0^{y_3}\varphi(y_4)\cdot d\,y_4 \\ &+\ldots \end{aligned} \qquad (48)$$

where

$$\begin{aligned}\varphi(y_1) &= \frac{2}{\pi}\int_0^\infty \cos(x\,\lambda)\cdot\cos(y_1\,\lambda)\cdot d\,\lambda \\ &= \frac{d}{d\,y_1}\cdot\frac{2}{\pi}\int_0^\infty \frac{\cos(x\,\lambda)\cdot\sin(y_1\,\lambda)}{\lambda}\,d\,\lambda \qquad (49) \\ &= \frac{d}{d\,y_1}\,\psi(y_1)\end{aligned}$$

Now the integral of (46) is by (48)

$$\begin{aligned}&\int_0^y \Phi(y_1)\cdot d\,y_1 \\ &\quad= \int_0^y \varphi(y_1)\cdot d\,y_1 \\ &\qquad+ \frac{b^2}{1\,!}\int_0^y \frac{y_1}{2}\,d\,y_1\int_0^{y_1} \varphi(y_2)\cdot d\,y_2 \\ &\qquad+ \frac{b^4}{2\,!}\int_0^y \frac{y_1}{2}\,d\,y_1\int_0^{y_1} \frac{y_2}{2}\,d\,y_2\cdot\int_0^{y_2} \varphi(y_3)\cdot d\,y_3 \\ &\qquad+\ldots\end{aligned}$$

which sum up to

$$\begin{aligned}\int_0^y \Phi(y_1)\cdot d\,y_1 &= \int_0^y \varphi(y_1)\cdot I_0\left(b\sqrt{y^2 - y_1^2}\right)d\,y_1 \\ &= \int_0^y \frac{d}{d\,y_1}\,\psi(y_1)\cdot I_0\left(b\sqrt{y^2 - y_1^2}\right)\cdot d\,y_1 \qquad (50)\end{aligned}$$

Now $\psi(y_1)$ is a discontinuous function which is zero before, unity after $y_1 = x$. Hence the definite integral of (50) is identically zero for values of the upper limit $y < x$, and its total contribution is entirely concentrated at $y_1 = x$.

Hence

$$\begin{aligned}\int_0^y \Phi(y_1)\cdot d\,y_1 &= 0 \text{ for } y = v\,t < x \\ &= I_0\left(b\sqrt{y^2 - x^2}\right) \text{ for } y \geq x \qquad (51)\end{aligned}$$

Hence by (**44**) and (**45**) our solution is:

$$A_x(t) = 0 \qquad \text{for} \qquad y = v\,t < x$$

$$= \sqrt{\frac{C}{L}} \cdot \epsilon^{-ay} \cdot I_0\left(b\sqrt{y^2 - x^2}\right)$$

$$+ (a-b)\int_x^y \sqrt{\frac{C}{L}}\,\epsilon^{-ay_1} \cdot I_0\left(b\sqrt{y_1^2 - x^2}\right)\cdot d\,y_1 \qquad \text{for} \quad y \geq x \qquad (52)$$

which is the final solution.

In the foregoing solution, we have dealt with discontinuous functions and doubtless some of the processes involved require further examination and justification from a purely mathematical standpoint. The final solution is, however, quite correct, and may be verified as the limit of formula (**32**); a solution to whose derivation no exception can be taken.

Special cases of the general solution will now be considered.

If leakage is absent $G = 0$ and $a = b$ whence

$$A_x(t) = 0 \qquad \text{for} \qquad v\,t = y < x$$

$$= \sqrt{\frac{C}{L}}\,\epsilon^{-ay} \cdot I_0\left(b\sqrt{y^2 - x^2}\right) \qquad \text{for } y \geq x \qquad (53)$$

$$= \sqrt{\frac{C}{L}}\,\epsilon^{-\rho t} \cdot I_0\left(\rho\sqrt{t^2 - \frac{x^2}{v^2}}\right) \quad \text{for} \quad t \geq \frac{x}{v}$$

which is the solution for the *leakageless line.** While the general solution (**52**) is original, the special solution (**53**) was previously derived by Heaviside by his operational method.

If $\frac{R}{L} = \frac{G}{C}$, $b = 0$ and the solution reduces to

$$A_x(t) = 0 \qquad \text{for } y < x$$

$$= \sqrt{\frac{C}{L}}\,\epsilon^{-ax} \qquad \text{for } y \geq x \qquad (54)$$

which is the solution for the *distortionless* line.

If $R = G = 0$, $a = b = 0$ and

$$A_x(t) = 0 \qquad \text{for } y < x$$

$$= \sqrt{\frac{C}{L}} \quad \text{for } y > x \qquad (55)$$

---

*See Note 8.

which is the solution for the non-dissipative line.

In all cases the current is propagated with a true finite velocity $v = \dfrac{1}{\sqrt{LC}}$ and is identically zero until $t = \dfrac{x}{v}$. When we come to examine the solution for the artificial line we shall see that there is no true velocity of propagation in an exact sense, but that there is a *virtual* velocity $\dfrac{1}{\sqrt{LC}}$ just as in the corresponding smooth line.

If $L = 0$, the solution is derivable from (**52**) by the method of limits. It is

$$A_x(t) = \sqrt{\frac{C}{\pi R}} \cdot \frac{\epsilon^{-\frac{RCx^2}{4t}}}{\sqrt{t}} \cdot \epsilon^{-\frac{G}{C}t}$$
$$+ \frac{G}{C}\sqrt{\frac{C}{\pi R}} \int_0^t \epsilon^{-\frac{G}{C}t_1} \cdot \frac{\epsilon^{-\frac{RCx^2}{4t_1}}}{\sqrt{t_1}}\, dt_1 \tag{56}$$

which is the solution for the *leaky cable*. Observe that here we have no finite velocity of propagation owing to the absence of inductance.

If the leakage G as well as the inductance L is zero, we get

$$A_x(t) = \sqrt{\frac{C}{\pi R}} \, \frac{\epsilon^{-\frac{RCx^2}{4t}}}{\sqrt{t}} \tag{57}$$

which is the Kelvin-Heaviside solution.

IV A. Solution for the Voltage Formulas for Smooth Line

Of almost equal importance and interest are the formulas for the voltage existing at any point x and time t on a smooth line of infinite length when a unit voltage is applied to the line at $x = 0$ and $t = 0$. The corresponding formulas for the artificial line are deducible from the current or indicial admittance formulas, but they are of complicated form and their consideration is omitted for the present.

We denote by $V_x(t)$ the voltage at point x and time t when a unit voltage is applied to the line at $x = t = 0$, and start with the differential equation of the line,

$$C \frac{d}{dt} V + G V = - \frac{d}{d x} I$$

where V and I are perfectly general. This equation may be integrated in the form:

$$V = - \frac{1}{C} \epsilon^{-(\rho-\sigma) t} \int_0^t \epsilon^{(\rho-\sigma)\lambda} \cdot \frac{d}{d x} I(\lambda) \cdot d\lambda$$

If $I(t)$ is the current due to unit d-c. voltage applied at $x = t = 0$ it is of course $A_x(t)$ as given by formula (52) and the corresponding voltage is $V_x(t)$. Substituting $A_x(\lambda)$ as given by (52) for $I(\lambda)$ in the integral and paying due regard to the discontinuous character of $A_x(\lambda)$ we get:

$$\begin{aligned} V_x(t) &= 0 \qquad \text{for } v t < x \\ &= \epsilon^{-ax} \\ &\quad + b^2 x \int_x^y \frac{\epsilon^{-a y_1} I_1 (b \sqrt{y_1^2 - x^2})}{b \sqrt{y_1^2 - x^2}} d y_1 \end{aligned} \tag{58}$$

which is the required solution. $I_1(b \sqrt{y^2 - x^2})$ is the Bessel function of order unity and pure imaginary argument $i b \sqrt{y^2 - x^2}$ tables of which exist and whose computation is quite simple.

If leakage is absent, $G = 0$ and $b = a$ in the above formula. In this case the solution may be conveniently written,

$$\begin{aligned} V_x(t) &= 0 \qquad \text{for } T < A \\ &= \epsilon^{-A} + A \int_A^T \frac{\epsilon^{-T_1} \cdot I_1 (\sqrt{T_1^2 - A^2})}{\sqrt{T_1^2 - A^2}} d T_1 \end{aligned} \tag{59}$$

where

$$A = \frac{R}{2} \sqrt{\frac{C}{L}} x$$

$$T = \frac{R}{2 L} t = \rho t$$

If $L = 0$ but the other three line constants are finite, the formula becomes, by approaching the limit $L = 0$,

$$V_x(t) = x \sqrt{\frac{R C}{4 \pi}} \int_0^t \frac{\epsilon^{-\frac{G}{C} t_1} \cdot \epsilon^{-\frac{R C x^2}{4 t_1}}}{t_1^{3/2}} d t_1 \tag{60}$$

which is reducible to the form

$$V_x(t) = \epsilon^{-\alpha x} - \frac{2}{\sqrt{\pi}} \int_0^{\sqrt{\frac{R C x^2}{4 t}}} \epsilon^{-\left(\lambda^2 + \frac{\alpha^2}{4 \lambda^2}\right)} \cdot d\lambda \qquad \textbf{(61)}$$

where $\alpha = \sqrt{R G}$

These are the formulas for the *leaky cable.*

If finally both G and L are zero

$$V_x(t) = 1 - \frac{2}{\sqrt{\pi}} \int_0^{\sqrt{\frac{R C x^2}{4 t}}} \epsilon^{-\lambda^2} \cdot d\lambda \qquad \textbf{(62)}$$

a formula which was first derived by Heaviside.

V. Approximate Solution for Loaded Cable

The loaded cable is defined as a non-inductive, leakageless line ($L = G = 0$) with load coils of pure inductance L inserted in series with the lines at periodic intervals. The exact solution for this structure has not yet been worked out, as it presents a problem of enormous complexity incapable of treatment by the direct methods employed in dealing with the smooth and artificial lines in the preceding section of this paper. The writer has applied a functional method of treatment, involving integral equations, to the problem which gives good promise of yielding a formal solution. This investigation has, however, not been completed, and as yet gives little hope of resulting in a practical working solution.

Fortunately, however, the close relationships obtaining between the loaded cable and the corresponding smooth and artificial lines has enabled me to arrive at a quasi-empirical solution, which very closely represents the facts, although it is not functionally exact.

To arrive at this solution, we remark that physically the loaded cable, as defined above, is intermediate between the corresponding smooth and artificial lines, and its solution must to a certain extent share the properties of the known solutions of the corresponding lines. More exactly, the required solution must satisfy the following conditions:

1. It must be asymptotic to the solution of the correspond-

ing smooth line as t approaches infinity. That is, it must approach formula (**53**) and ultimately (**57**) as t approaches infinity.

2. It must degenerate into formula (**35**) for the non-dissipative artificial line as the distributed resistance of the cable approaches zero.

3. It must degenerate into formula (**57**) for the smooth cable as the load coil inductance L approaches zero.

4. It must degenerate into formula (**53**) for the smooth line as the load coil inductance L and the distributed resistance R and capacity C per section all approach zero while the number of sections approach infinity.

5. It must give the correct virtual velocity of propagation of the structure and correctly formulate the steady state characteristics in accordance with formula (**13**).

Such a function is the following:

$$\sqrt{\frac{C}{L}}\,\epsilon^{-\rho t}\cdot I_0\left(\sqrt{(\rho\, t)^2-A^2}\right)\cdot\frac{\epsilon^{hA}}{\operatorname{sech}\left(\frac{h\,A}{2\,q}\right)}\int_0^{2vt}\epsilon^{-\lambda\,\cdot\,\sinh\left(\frac{h\,A}{2\,q}\right)}\cdot J_{2q}(\lambda)\cdot d\,\lambda \qquad (\mathbf{63})$$

Where in accordance with previous notation

$$\rho=\frac{R}{2\,L}\text{ and }\quad v=\frac{1}{\sqrt{L\,C}}\quad\text{ and }\quad A=\frac{R\,q}{2}\sqrt{\frac{C}{L}}$$

This is the required quasi-empirical formula for the current in the q^{th} section or load coil of a loaded cable in response to a unit d-c. voltage applied at mid-load position at time $t=0$. R, C, and L, are the constants *per section* of the structure. The first two being distributed and the last concentrated in the load coil. For values of R. L. and C. encountered in practice: formula (**62**) may be replaced by

$$\sqrt{\frac{C}{L}}\,\epsilon^{-\rho t}\cdot I_0\left(\sqrt{(\rho\, t)^2-A^2}\right)\cdot\epsilon^{hA}\cdot\int_0^{2vt}\epsilon^{-\frac{h\,A}{2\,q}\lambda}\,J_{2q}(\lambda)\cdot d\,\lambda \qquad (\mathbf{64})$$

The symbol h which disappears in the first four limiting cases listed above, is a numeric. When assigned the value ½, formula (**62**) gives the steady state characteristics with a good degree of approximation.

The foregoing formulas, while not functionally exact, and which are indeed, empirical, represent the phenomena with sufficient exactness for engineering purposes and have been verified as closely as could be expected by oscillographic tests. The physical character of the solution will be discussed and illustrated by curves in the succeeding section.

VI. Numerical Solution of Formulas and Discussion of Curves

By virtue of the mathematical analysis of the preceding sections we are now in possession of a fairly systematic formulation of the general problem, and in particular of the formulas which determine the progress and distortion of electric waves in transmission systems. While the phenomena are reduced to their simplest possible formulation they are still so complex and the line constants are involved in such a complicated manner that an understanding of the inner meaning of the solutions requires that analysis be superseded at this stage by a systematic and comprehensive program of computation and study of the resulting numerical solutions, when plotted in the form of curves. Such a systematic study is beyond the scope of the present paper and would indeed occupy a whole treatise in itself. We shall, however, exhibit a representative series of numerical solutions in the form of curves, and briefly discuss the physical character of the phenomena which they represent.

Restricting attention to the line formulas 32–64, their evaluation depends on the numerical computation of Bessel functions and the integration of definite integrals. The latter operation presents no difficulties and the integrations are easily and accurately effected, once the integrands are computed and plotted as time functions, by means of a Coradi integraph which traces the progressive values of the integrals. Fortunately, also, the Bessel functions, which are of such great importance in so many branches of mathematical physics, have been the subject of exhaustive study and tabulation. While no tabulations exist for the high orders of functions which we require, their computation is effected without any serious difficulty from the asymptotic formulas of Nicholson.

We shall first consider the artificial line formulas (32–36) and since one of the prime objects of our investigation is an examination of the correspondence existing between the artificial and smooth line, the corresponding functions for the smooth line are plotted to the same scale on the same sheet. We shall have frequent occasion in discussing the artificial and the periodically loaded lines to refer to the "corresponding smooth line," which we define as the line having continuously distributed constants of the same aggregate value as the lumped constants of the artificial line. Thus if R, L, C, G, denote the constants *per section* of the artificial or periodically loaded line and the current in the qth section is under consideration, the corresponding smooth line has constants R, L, C, G per *unit length* and the current at point $x = q$ is the corresponding current.

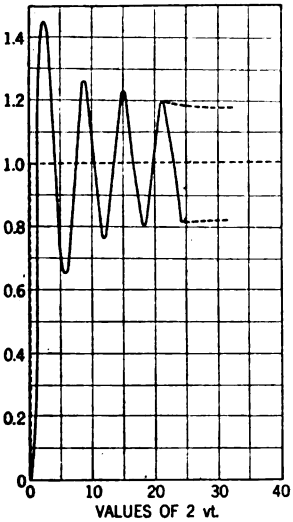

FIG. 1—[COMPUTED FROM FORMULA (35)] CURRENT ENTERING LOADED CABLE

Non-dissipative: $R = G = O$. Multiply ordinates by $\sqrt{C/L}$

Figs. 1, 2, 3 and 4 are graphs of formula (35) for $q = 0$, 200, 1000 and 2000 respectively and thus represent the current in the initial, the 100th, the 500th and the 1000th sections of the non-dissipative artificial line or periodically loaded cable. It will be understood that the line is infinitely long and that a unit d-c. voltage applied to the line at mid-load position and at time $t = 0$ is assumed. A study of the non-dissipative line, which of course is ideal and unrealizable, is nevertheless of practical importance because in this type of line the effect of the discontinuous loading of the periodically loaded cable is isolated and thereby exhibited in the clearest possible manner.

The dotted curves represent the current in the corresponding smooth line as computed from formula (**55**). For the smooth line, the current, as we see, is discontinuous, being identically zero for a time $v\,t = q$ and having an instantaneous jump to its final value $\sqrt{\frac{C}{L}}$ at $v\,t = q$. The current in the artificial line differs from that in the corresponding smooth line in three important respects; (1) the absence of the abrupt discontinuous wave front; (2) the presence of superposed oscillations and (**3**) *the absence of a true finite velocity of propagation.* It will be observed, however, that the current in any section is negligibly small or even sensibly zero until $v\,t = q$, so that the current is propagated with a *virtual* velocity $\frac{1}{\sqrt{L\,C}}$ per section. The presence of a well marked wave front is also evident although this is not abrupt, as in the smooth line. The effective slope of the wave front becomes smaller as the current wave travels out on the line decreasing noticeably as the number of sections is increased. When the number of sections becomes large,

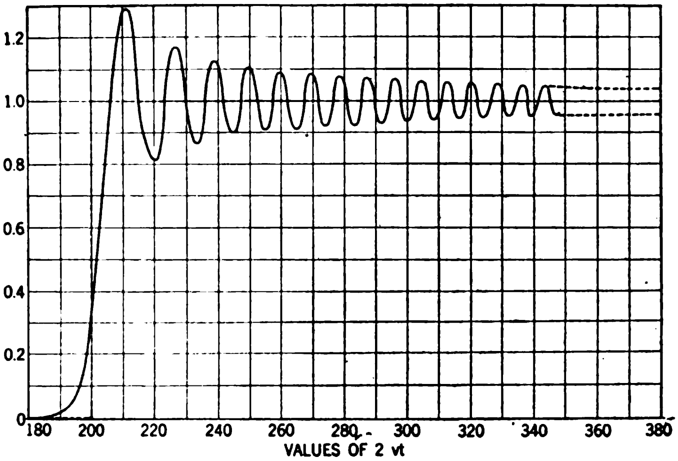

FIG. 2—[COMPUTED FROM FORMULA (35)] CURRENT IN 100TH SECTION OF ARTIFICIAL LINE

Non-dissipative: $R = G = O$. Multiply ordinates by $\sqrt{C/L}$

however, the decrease in the slope is not rapid, being in the 500th section about 60 per cent of that in the 100th section.

The superposed oscillations are of interest. These are initially of a frequency depending upon and decreasing with the number of sections, q, but in all sections ultimately attaining the frequency $\frac{1}{\pi\sqrt{LC}} = \frac{v}{\pi}$ which is the critical or cut-off frequency of the line, above which steady-state currents are attenuated during transmission and below which they are unattenuated. When $v\,t$ is large compared with q the amplitude of these oscillations becomes $\sqrt{\frac{1}{\pi v t}}$ so that they ultimately die away and the current approaches the value $\sqrt{\frac{C}{L}}$ for all sections. The current in the loaded cable is thus asymptotic to the current in the corresponding smooth line and oscillates about it with diminishing amplitude and increasing frequency.

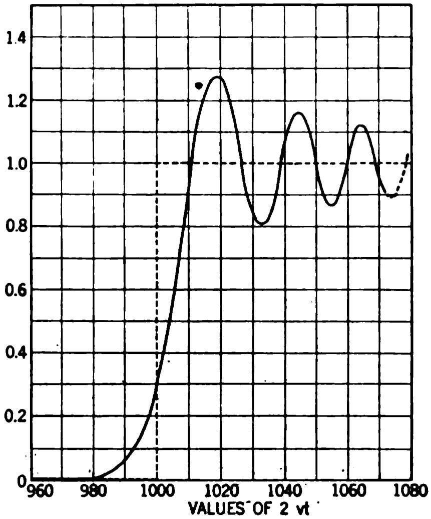

FIG. 3—[COMPUTED FROM FORMULA (35)] CURRENT IN 500TH SECTION OF ARTIFICIAL LINE

Non-dissipative: $R = G = O$. Multiply ordinates by $\sqrt{C/L}$

Since the abscissas of these curves represent values of

$2vt = \frac{2}{\sqrt{LC}} t$, and the ordinates are to be multiplied by $\sqrt{\frac{C}{L}}$ to translate into actual values, the curves are of universal application for all values of the constants L and C.

The additional effect of resistance in the artificial line is exhibited in Figs. 5, 6 and 7 which are computed from formula (**33**) for $q = 100$. They therefore represent the current in the 100th section of an artificial line without leakage for three different values of R/L per section. The current functions (or indicial admittances) for the corresponding smooth lines, computed from formula (**53**) are plotted on the same sheet. Curves 5, 6 and 7 correspond to values of $\frac{R}{2}\sqrt{\frac{C}{L}}\,q$ of 2.65, 5.29 and 14.75 respectively; $\frac{R}{2}\sqrt{\frac{C}{L}}\,q$ is the exponential attenuation factor and an examination of the curves shows that, for the smooth line, the discontinuous wave front is attenuated by this factor during transmission. For values of $\frac{R}{2}\sqrt{\frac{C}{L}}\,q$ greater than two, the tail of the wave exceeds in

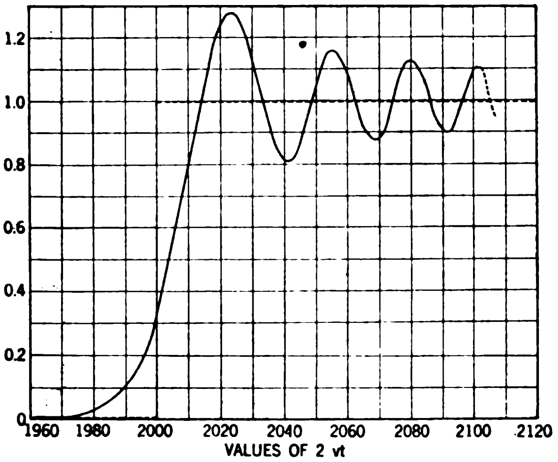

Fig. 4—[Computed from Formula (35)] Current in 1000th Section of Artificial Line

Non-dissipative: $R = G = O$. Multiply ordinates by $\sqrt{C/L}$

amplitude the head. For large values of $\frac{R}{2} \sqrt{\frac{C}{L}}\, q$ (see curve 7) the head of the wave is insignificant compared with the tail. It should be observed that curves 5, 6 and 7 are plotted in a scale to exhibit the character of the wave in the neighborhood of the head and do not show the way the tail builds up to its maximum and ultimately dies away. The tail of the wave builds up more and more slowly as $\frac{R}{2} \sqrt{\frac{C}{L}}\, q$ is increased and ultimately dies away in accordance with the law $\sqrt{\frac{C}{\pi R t}} \cdot \epsilon^{-\frac{RC}{4t} q^2}$. This will be recognized as the non-inductive cable formula (57) so that the line ultimately behaves like the cable to d-c. impressed voltages. Its behavior to alternating voltages is entirely different, however, as may be inferred from the difference in the curves in the neighborhood of the wave head.

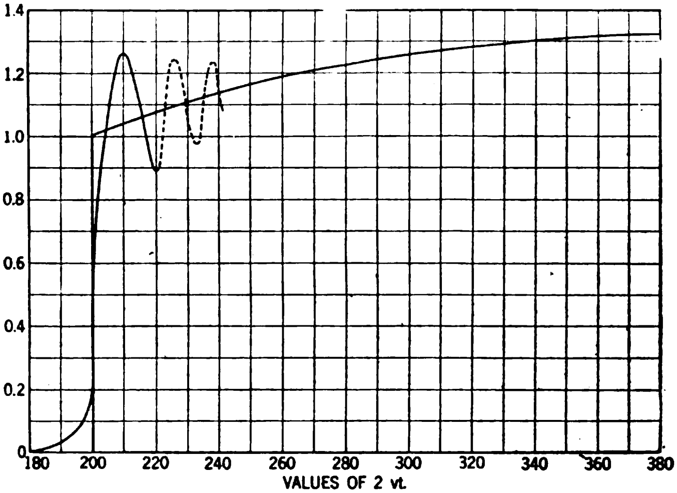

FIG. 5—[COMPUTED FROM FORMULA (33)] CURRENT IN 100TH SECTION OF ARTIFICIAL LINE

Line constants: $R/2 \sqrt{C/L} = 0.02646$. Multiply ordinates by $\epsilon^{-2.646 \sqrt{C/L}}$

$G = 0$

As regards the artificial line curves, we see that, precisely as in curves 1, 2, 3 and 4, they oscillate about the corresponding

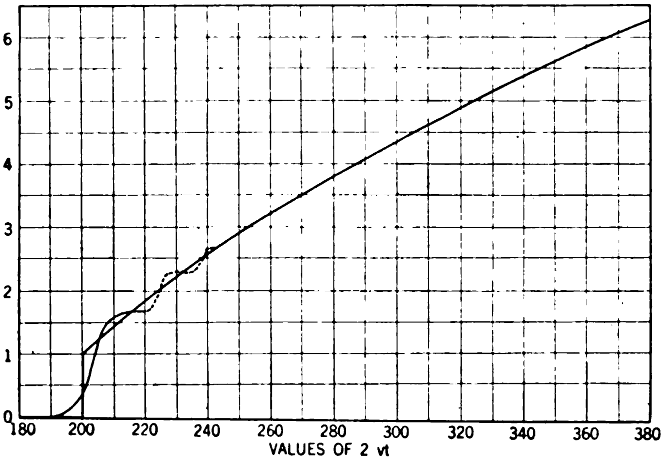

FIG. 6—[COMPUTED FROM FORMULA (33)] CURRENT IN 100TH SECTION OF ARTIFICIAL LINE

Line constants: $R/2\sqrt{C/L}=0.05291$. Multiply ordinates by $\epsilon^{-5.291}\sqrt{C/L}$

$G=0$

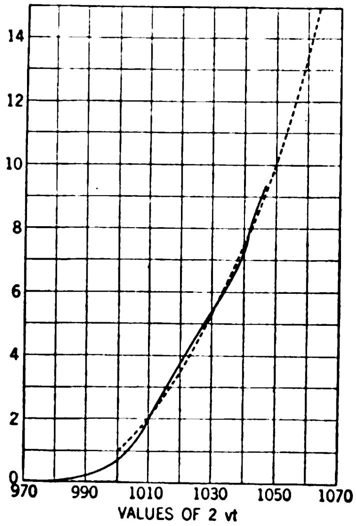

FIG. 7—[COMPUTED FROM FORMULA (33)] CURRENT IN 500TH SECTION OF ARTIFICIAL LINE

Line constants: $R/2\sqrt{C/L}=0.0295$. Multiply ordinates by $\epsilon^{-14.75}\sqrt{C/L}$

$G=0$

smooth line curves and ultimately coalesce therewith. They are distinguished, also, by the absence of the abrupt wave head and the presence of the superposed oscillations. The same virtual velocity per section $\frac{1}{\sqrt{LC}}$ exists independently of the resistance but the superposed oscillations diminish in relative amplitude as $\frac{R}{2}\sqrt{\frac{C}{L}}\,q$ is increased, as is clear from a comparison of curves 5, 6 and 7.

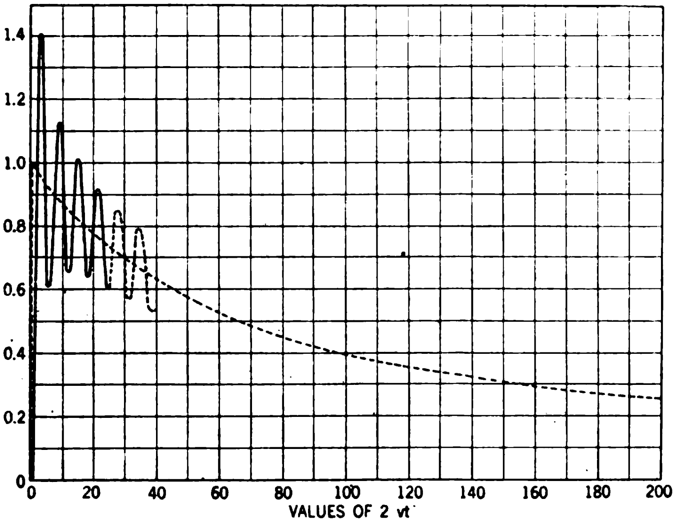

FIG. 8—[COMPUTED FROM FORMULA (62)] CURRENT ENTERING LOADED CABLE

Cable constants: $R/2\sqrt{C/L} = 0.02646$. Multiply ordinates by $\sqrt{C/L}$
$G = 0$

Some typical loaded cable curves computed from formula (63) are shown in Figs. 8, 9, 10 and 11. Curves 8 and 9 are plots of the current entering the cable (corresponding to a unit d-c. voltage impressed at mid-load position) for two different values of $\frac{R}{2}\sqrt{\frac{C}{L}}$ (0.01323 and 0.02646 respectively) while curves 10 and 11 show the current in the 100th load coil for two different values of $\frac{R}{2}\sqrt{\frac{C}{L}}\,q$ (2.65 and 5.291 respectively). The corresponding smooth line current curves are shown in dotted lines. The difference between the curves for the loaded cable and the corresponding artificial line is quite small except for fairly large values of $\frac{R}{2}\sqrt{\frac{C}{L}}\,q$ (greater than three) and consists in a slower damping out of the superposed oscillations. This is precisely the kind of effect we should expect when we recall the fact that the attenuation of alternating currents for large values of $\frac{R}{2}\sqrt{\frac{C}{L}}\,q$ is much smaller in loaded cables than in artificial lines. At the same time it must be remembered that the loaded cable under consideration is ideal in that the loading coils are assumed as pure inductances without resistance. In practise the resistance of the loading coils would modify the current curves, which are actually (as has been shown by oscillographic tests) intermediate in character between the theoretical curves for the artificial line and the ideal periodically loaded cable.

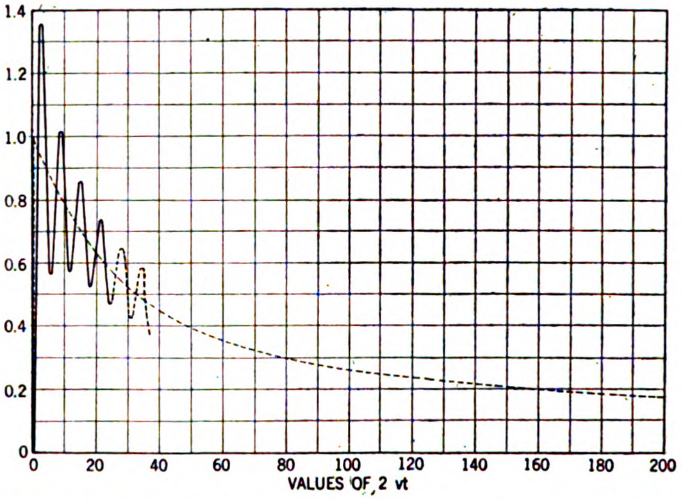

Fig. 9—[Computed from Formula (62)] Current Entering Load Cable

Cable constants: $R/2\ \sqrt{C/L} = 0.529$. Multiply ordinates by $\sqrt{C/L}$

$G = 0$

The effect of leakage in the artificial line (when so proportioned as to make $\frac{G}{C} = \frac{R}{L}$) is shown in Figs. 12 and 13

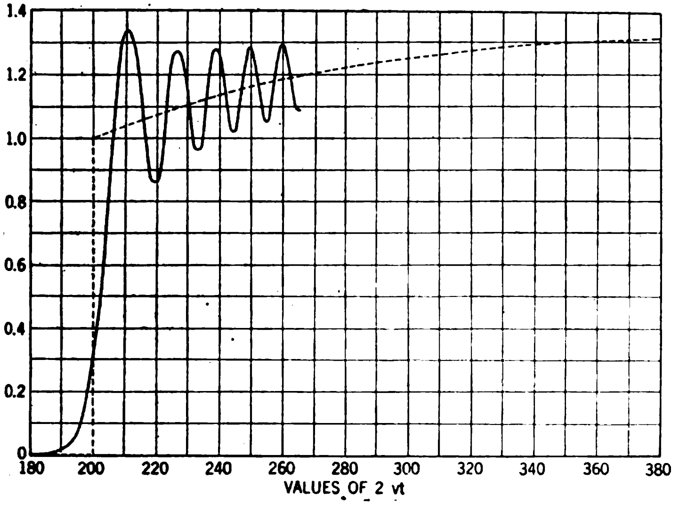

Fig. 10—[Computed from Formula (162)] Current in 100th Section of Loaded Cable

Cable constants: $R/2 \sqrt{C/L}=0.02646$. Multiply ordinates by $\epsilon^{-2.646\sqrt{C/L}}$

$G=0$

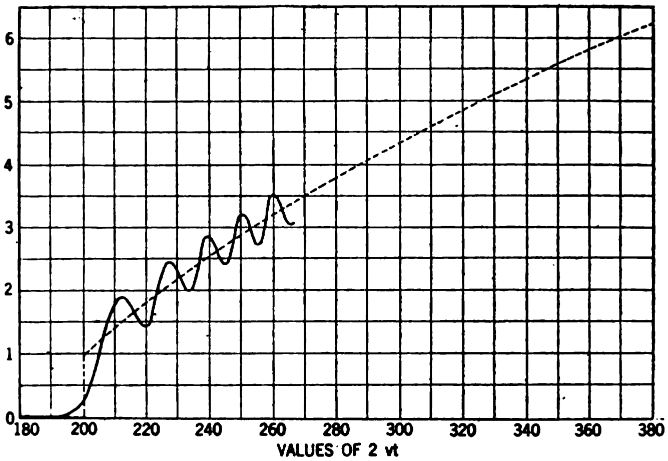

Fig. 11—[Computed from Formula (62)] Current in 100th Coil of Loaded Cable

Cable constants: $R/2 \sqrt{C/L}=0.05291$. Multiply ordinates by $\epsilon^{-5.291\sqrt{C/L}}$

$G=0$

which are computed from formula (**34**) for the quasi-distortionless artificial line. Curve 12 exhibits the current in the 100th and curve 13 in the 500th section. The corresponding smooth lines are, of course, exactly distortionless. The artificial lines while not strictly distortionless, are characterized, as compared with the same lines without leakage, by the reduction of the tail of the wave to the same magnitude as the head, and a rapid damping out of the superposed oscillations.

The effect of leakage on the smooth line curve is exhibited in Fig. 14 which is computed from formula (**52**). The final direct current value is indicated by the dotted line. Comparison of Fig. 14 with preceding curves shows the effect of the leakage in reducing the tail and relatively enlarging the head of the wave.

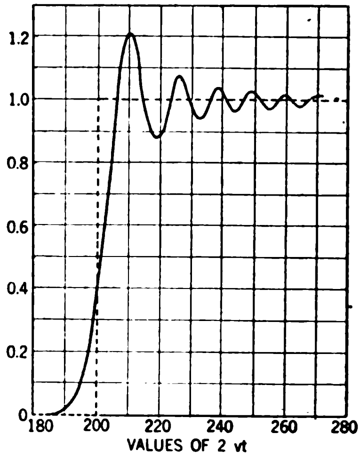

FIG. 12—[COMPUTED FROM FORMULA (34)] CURRENT IN 100TH SECTION OF ARTIFICIAL LINE

Line constants: $R/2\sqrt{C/L} = 0.02646$. Multiply ordinates by $\epsilon^{-5.291\sqrt{C/L}}$

$R/L = G/C$

The curves of Figs. 15 and 16, computed from formulas (**53**) and (**57**) respectively are plots of the current waves in the smooth line of attenuation $A = 10$, and in the non-inductive cable of the same total resistance and capacity. The curves are plotted to the same argument $\frac{4\,t}{R\,C \times 2}$ in order to facilitate comparison. Referring to Fig. 15, the large value of the attenuation makes the discontinuous head of the wave quite negligible in comparison with the tail, and it will be seen that the head of the wave is not distinguishable on the scale to which the ordinates are drawn. In fact for lines of this or greater order of attenuation the inductance plays a quite minor role when the applied voltage is uniform except that its presence results in a finite velocity of propaga-

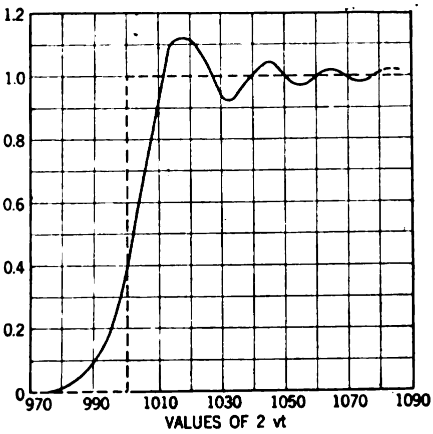

FIG. 13—[COMPUTED FROM FORMULA (34)] CURRENT IN 500TH SECTION OF ARTIFICIAL LINE

Line constants: $R/2\sqrt{C/L}=0.02646$. Multiply ordinates by $\epsilon^{-26.46\sqrt{C/L}}$

$R/L=G/C$

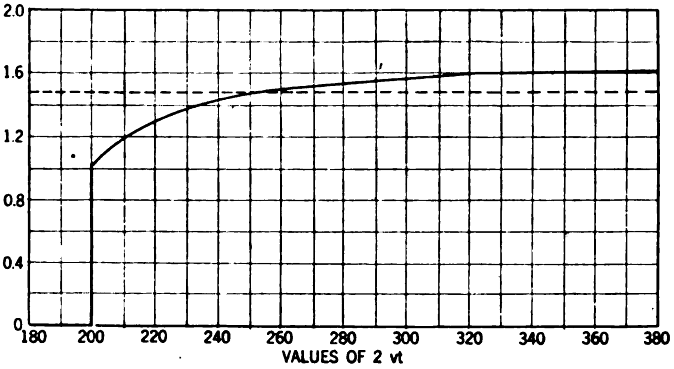

FIG. 14—[COMPUTED FROM FORMULA (52)] CURRENT AT POINT $X=100$ OF CONTINUOUSLY LOADED LINE

Line constants: $R/2\sqrt{C/L}+G/2\sqrt{L/C}=0.0706$. Multiply ordinates by $\epsilon^{-7.06\sqrt{C/L}}$

$R/2\sqrt{C/L}-G/2\sqrt{L/C}=0.0353$

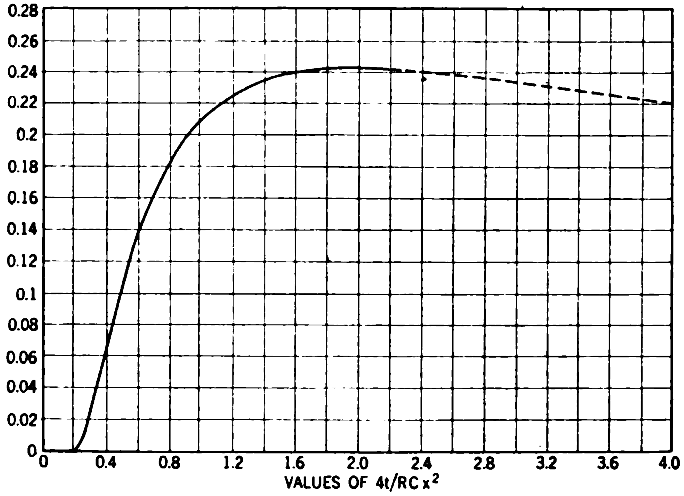

FIG. 15—[COMPUTED FROM FORMULA (53)] CURRENT AT POINT *X* OF SMOOTH LINE

Line constants: $R/2\sqrt{C/L}\ X = 10$ Multiply ordinates by $2/RX$

$G = 0$

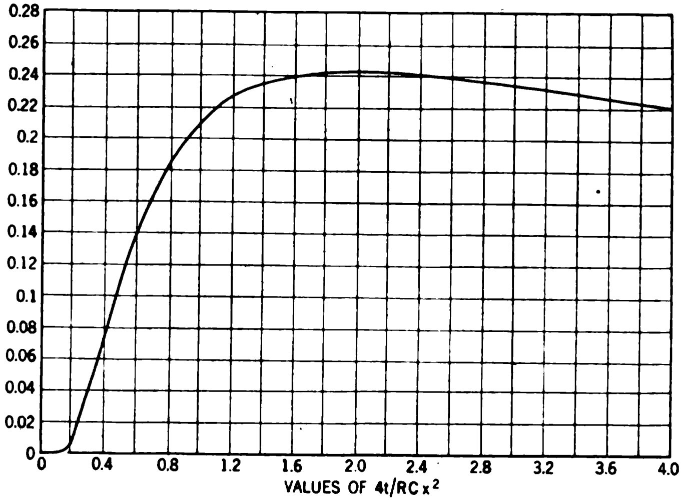

FIG. 16—[COMPUTED FROM FORMULA (57)] CURRENT AT POINT *X* OF SMOOTH CABLE (*R*, *C*)

Multiply ordinates by $2/RX$

tion, whereas in the non-inductive cable velocity is infinite. Otherwise the current waves, as may be seen by comparison of Figs. 15 and 16, are almost identical.

The artificial cable behaves very closely like the corresponding smooth non-inductive cable if the number of sections is not too small. This may be shown quite simply from formulas (**36**) and (**57**). If we set

$$\frac{4\,t}{R\,C\,x^2} = \frac{4\,t}{R_0\,C_0} = u$$

formula (**57**) becomes

$$\begin{aligned} A_x(t) &= \frac{2}{\sqrt{\pi}\,R_0}\,\frac{1}{\sqrt{u}}\,\epsilon^{-1/u} \\ &= \frac{2}{\sqrt{\pi}\,R_0}\cdot\frac{1}{\sqrt{u}} \\ &\quad \left\{1-\frac{1}{1\,!\,u}+\frac{1}{2\,!\,u^2}-\frac{1}{3\,!\,u^3}\;\cdots\cdots\right\} \qquad \textbf{(a)} \end{aligned}$$

Here, of course, R_0 and C_0 denote the total value of the line constants in the length x of the line.

If the corresponding artificial line is made up of q sections, the constants per section are R_0/q and C_0/q and formula (**36**) becomes,

$$A_q(t) = \frac{2\,q}{R_0}\,\epsilon^{-\frac{q^2 u}{2}}\cdot I_q\left(\frac{q^2 u}{2}\right)$$

Expanding the Bessel function in its asymptotic form:

$$\begin{aligned} A_q(t) = \frac{2}{\sqrt{\pi}\,R_0}\,\frac{1}{\sqrt{u}} &\left\{1-\frac{1}{1\,!\,u}\left(1-\left(\frac{1}{2\,q}\right)^2\right)\right. \\ &+\frac{1}{2\,!\,u^2}\left(1-\left(\frac{1}{2\,q}\right)^2\right)\left(1-\left(\frac{3}{2\,q}\right)^2\right) \\ &-\frac{1}{3\,!\,u^3}\left(1-\left(\frac{1}{2\,q}\right)^2\right)\left(1-\left(\frac{3}{2\,q}\right)^2\right) \\ &\qquad\qquad \left(1-\left(\frac{5}{2\,q}\right)^2\right)\cdots\cdots \qquad \textbf{(b)} \\ &\left. +\;\cdots\cdots\cdots\cdots \right. \end{aligned}$$

Comparison of (**a**) and (**b**) shows that, except for very small values of the argument u the artificial cable simulates the corresponding smooth cable quite closely if q is not too small. The departure between the two formulas decreases very rapidly as either u or q is increased in value. We observe, therefore, that the non-inductive cable admits of mush closer simulation by an artificial structure than does the transmission line which includes inductance as well as resistance and capacity.

The curves of Figs. 17, 18 and 19 exhibit the voltage waves on smooth lines, curves 17 and 18 being computed from formula (**59**) while curve (19) is plotted from formula (**58**) and exhibits the additional effect of leakage. Referring to Figs. 17 and 18 the voltage is identically zero until $T = A$ or $v\,t = x$, and has an instantaneous jump to the value ϵ^{-A}, after which it builds up slowly to its final value, unity. When leakage is present the wave head has likewise an instantaneous jump at $v\,t = x$, and thereafter builds up to its final value (shown by the dotted line in Fig. 19) $\epsilon^{-x\sqrt{RG}}$. The constants corresponding to curve 19 are so chosen as to make the line almost but not quite distortionless, the ratio ρ/σ being 5.

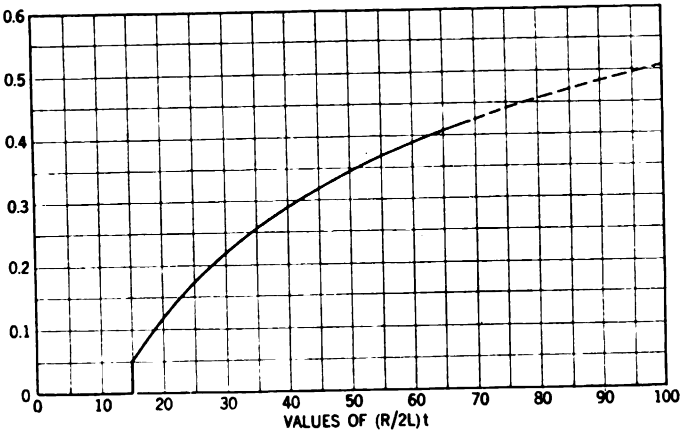

Fig. 17—[Computed from Formula (59)] Voltage on Continuously Loaded Line

Line constants: $R/2\sqrt{C/L}\,X = 3$
$G = 0$

The preceding curves all represent the current or voltage waves in response to a unit d-c. voltage applied to the line. Figs. 20 and 21 show how the current starts to build up when the line is excited by alternating voltages of two different frequencies. The line is the non-dissipative periodically loaded cable and the current is that existing in the 1000th section. Observe that in Fig. 21 the current has not yet attained ten per cent of its final steady state value, so that in this case the building up is very slow. These curves have been computed by special methods applicable to the non-dissipative loaded cable, which have proved considerably more rapid than the

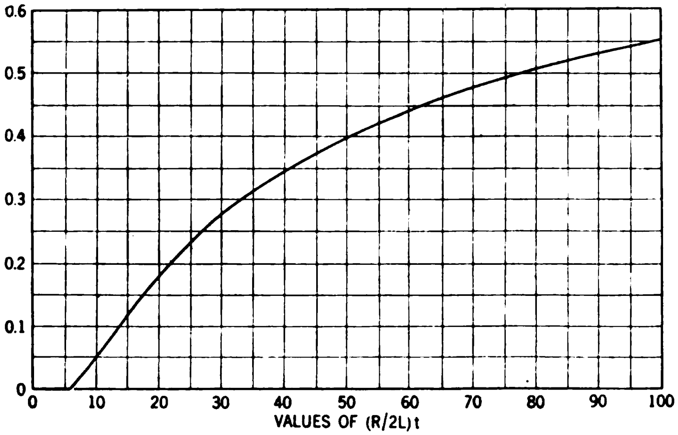

Fig. 18—[Computed from Formula (59)] Voltage on Continuously Loaded Line

Line constants: $R/2\sqrt{C/L}\,X=6$
$G=0$

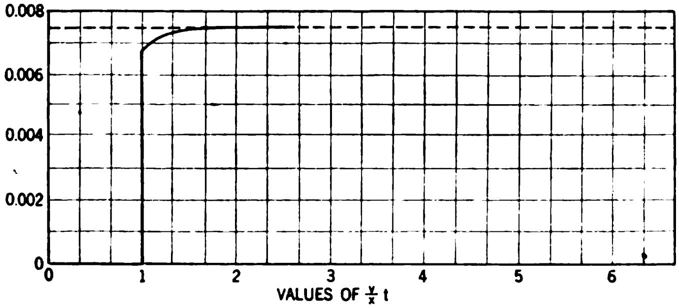

Fig. 19—[Computed from Formula (58)] Voltage on Continuously Loaded Line

Line constants: $R/2\sqrt{C/L}\,X=3$
$G/2\sqrt{L/C}\,X=2$

mechanical evaluation by the Coradi harmonic analyser as described in Section I. These special methods, however, are restricted to the non-dissipative loaded cable, and are therefore

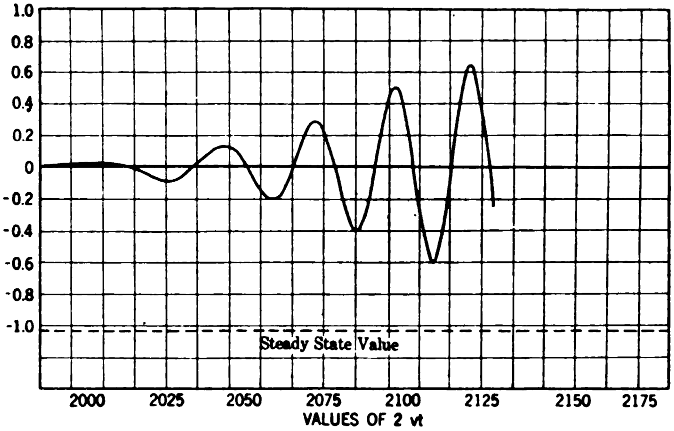

FIG. 20—CURRENT IN 100TH SECTION OF LOADED CABLE IN RESPONSE TO VOLTAGE COS pt

Non-dissipative: $R=G=0$. $f/f_c=0.25$. Multiply ordinates by $\sqrt{C/L}$

not of sufficient general interest to warrant their discussion here.

The foregoing discussion is merely suggestive and makes no pretense to more than point out briefly the prominent outstanding facts. It is hoped, however, that the discussion is full enough to show that a real interpretation and understanding of the complex phenomena of wave propagation is deducible from the formulas derived in this paper.

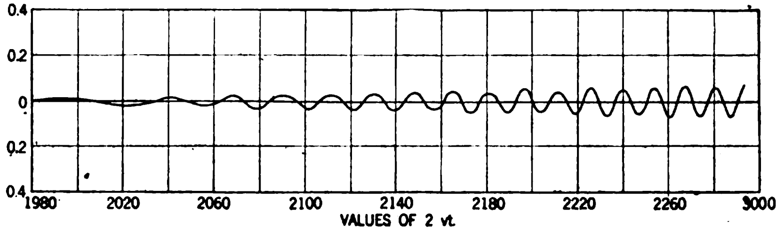

FIG. 21—CURRENT IN 1000TH SECTION OF LOADED CABLE IN RESPONSE TO VOLTAGE COS pt

Non-dissipative: $R=G=0$. $f/f_c=0.6283$. Steady state amplitude $=1.286$

VII. Application of Synthetic Method to Transmission Lines with Terminal Impedances

The synthetic method, developed and discussed in a previous part of this paper, is adapted to determine the effect of terminal apparatus in transmission systems, and indeed this is one of its chief uses. We shall now apply the method to the solution of a practical problem, and since we are concerned primarily with the method of treatment and not with detailed results, a relatively simple problem will be chosen to illustrate the method and its possibilities. A statement of the problem is as follows:

A smooth transmission line of given length and given constants has a unit d-c. voltage applied at $x = t = 0$, while the other end of the line is closed by the primary of a transformer the secondary of which is closed by a resistance R_2 of given value. What is the current in the secondary of the transformer; or in other words, what is the transfer indicial admittance of the system?

We denote the length of the line by s; its constants per unit length by R, L, and C (leakage is assumed absent); the primary and secondary inductances of the transformer (assumed as unity ratio and without magnetic leakage) by L_1; the unknown line current and voltage at $x = s$ by $I_s(t)$ and $V_s(t)$ respectively. We also denote by $A_1(t)$ and $A_2(t)$ the driving point and transfer indicial admittances of the line per se. These are then equal to the currents existing at $x = 0$ and $x = s$ respectively when a unit d-c. voltage is applied to the line at $x = 0$ and $t = 0$. By aid of formulas (**15**) and (**53**), $A_1(t)$ and $A_2(t)$ are given by

$$A_1(t) = \sqrt{\frac{C}{L}}\,\epsilon^{-\rho t}\left\{ I_0(\rho t) + 2 I_0\left(\rho\sqrt{t^2 - \left[\frac{2s}{v}\right]^2}\right) + 2 I_0\left(\rho\sqrt{t^2 - \left[\frac{4s}{v}\right]^2}\right) + \ldots \right\} \quad \textbf{(a)}$$

$$A_2(t) = 2\sqrt{\frac{C}{L}}\,\epsilon^{-\rho t}\left\{ I_0\left(\rho\sqrt{t^2 - \left[\frac{s}{v}\right]^2}\right) + I_0\left(\rho\sqrt{t^2 - \left[\frac{3s}{v}\right]^2}\right) + \ldots \right\} \quad \textbf{(b)}$$

In these formulas, I_0 denotes the Bessel function of order zero, and the successive terms of the series come into existence at the time when their arguments pass from imaginary to real values. For smaller values of the time they are to be regarded as identically zero since they represent successive reflected waves.

Now the line, regarded by itself, is actuated by a unit d-c. voltage applied at $x = 0$ and a voltage $V_s(t)$ applied at $x = s$ by formula (**16**) the current $I_s(t)$ existing at $x = s$ is given by

$$A_2(t) - \frac{d}{dt} \int_0^t V_s(\lambda) \, . \, A_1(t - \lambda) \cdot d\lambda \qquad \textbf{(c)}$$

Now this same current is that which enters the primary of the transformer which is connected across the line at $x = s$. We can therefore express this current as that entering the terminal apparatus in response to the voltage $V_s(t)$; it is then

$$\frac{1}{R_2} V_s(t) + \frac{1}{L_1} \int_0^t V_s(\lambda) \cdot d\lambda \qquad \textbf{(d)}$$

Equating (**c**) and (**d**) we get after simplification

$$V_s(t) = \left[\frac{R_2}{1 + R_2 A_1(0)}\right] . \left[A_2(t) - \int_0^t V_s(\lambda) \left\{ A'_1(t - \lambda) + \frac{1}{L_1} \right\} \cdot d\lambda\right] \qquad \textbf{(e)}$$

which is the integral equation in $V_s(t)$. Since the voltage across the secondary of the transformer is $V_s(t)$ also, the secondary current is simply

$$\frac{1}{R_2} V_s(t)$$

The numerical integration of this equation can, of course, be effected only when the numerical values of the constants of the problem are assigned. We take the following values.

$$R_2 = A_1(0) = \sqrt{\frac{C}{L}} = 1935 \text{ ohms}$$

$$L_1 = L_2 = 0.4 \text{ henrys}$$

$$\frac{R}{2L} = \quad = 292$$

$$v = \quad = 1.105 \times 10^4$$

$$s = 100$$

The results of the numerical integration of the equation are shown in Fig. 22 which is a plot of the voltage existing across the end of the line and hence is directly proportional to the current in the secondary of the terminal transformer. In this particular case the effect of the secondary reflections is insignificant and the voltage sensibly zero before the secondary reflected wave has arrived.

As a second example of the synthetic method we shall develop the solution for the voltage existing at the terminals of an infinitely long non-inductive cable when a unit d-c. voltage is applied at time $t = 0$ to the cable through a condenser C_0. This problem is not only of some practical importance but is of very great theoretical interest as well in that we are led not only to the formal solution but also to an asymptotic solution identical with that gotten by Heaviside by his remarkable "fractional differentiation." We shall have occasion, therefore, to discuss briefly Heaviside's mode of solution in this connection.

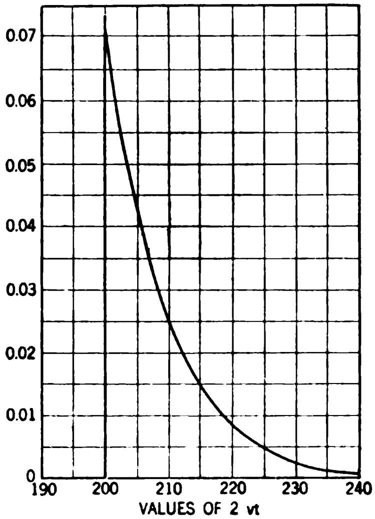

Fig. 22—[Computed From Formula (63)] Voltage Across Terminal Impedance on Smooth Line. For Data See Section VII

To proceed with the problem let R and C be the constants per unit length of the cable and C_0 the terminal condenser capacity. By formula (57) the indicial admittance of the o that, if $V(t)$ denote the required terminal

entering the cable is, by formula (**11**),

$$\overline{C}\over R \cdot \frac{d}{dt} \int_0^t d\lambda \cdot \frac{V(\lambda)}{\sqrt{t-\lambda}}$$

ıt is likewise equal to C_0 times the time rate voltage $1 - V(t)$ which exists across the

$$(t)\,) = \sqrt{\frac{C}{\pi R}}\;\frac{d}{dt} \int_0^t d\lambda\, \frac{V(\lambda)}{\sqrt{t-\lambda}}$$

$$1 - \sqrt{h} \int_0^t d\lambda \frac{V(\lambda)}{\sqrt{t-\lambda}} \qquad (\mathbf{a}_1)$$

$$= \frac{1}{C_0} \sqrt{\frac{C}{\pi R}}$$

teristic integral equation of our problem. this integral equation in the form of an n be made to depend on Dirichlet's formula,

$$\frac{d\lambda_1}{\sqrt{(t-\lambda_1)(\lambda_1-\lambda)}} = \pi$$

mula to our problem, multiply the integral ent λ) by $\frac{1}{\sqrt{t-\lambda}}$ and integrate between :his gives

$$\overline{h} \int_0^t d\lambda \cdot V(\lambda) \int_\lambda^t \frac{d\lambda_1}{\sqrt{(t-\lambda_1)(\lambda_1-\lambda)}}$$

$$= 2\sqrt{t} - \pi\sqrt{h} \int_0^t V(\lambda)\, d\lambda \qquad (\mathbf{b}_1)$$

ıla.

ıation, the integral equation is reducible to

$$\int^t V(\lambda) \cdot d\lambda = 1 - 2\sqrt{h\,t} \qquad (\mathbf{c}_1)$$

the formal solution of which is

$$V\,(t) \doteq \epsilon^{\pi h t} - \sqrt{h} \int_0^t d\,\lambda \cdot \frac{\epsilon^{\pi h \lambda}}{\sqrt{t-\lambda}}$$

This is the formal solution of the problem and might have been gotten directly from the original integral equation by the method of successive substitutions. The advantage of the method followed here is, however, that we have succeeded in reducing the original integral equation to the following differential equation which results from differentiating c_1 with respect to t:

$$V\,(t) - \frac{1}{\pi\,h}\;V'\,(t) = \frac{1}{\pi\,\sqrt{h\,t}}$$

.Now this differential equation admits of easy asymptotic solution by known methods; perhaps the simplest is to assume a solution of the form

$$V\,(t) \sim \frac{1}{\sqrt{t}}\;\left[\,a_0 + \frac{a_1}{t} + \frac{a_2}{t^2} + \frac{a_3}{t^3} + \ldots\,\right]$$

and identify the unknown coefficients by substitution in the differential equation and equation of like powers of t. Proceeding in this manner we get without any trouble the required asymptotic expansion:—

$$V\,(t) \sim \frac{1}{\pi\,\sqrt{h\,t}} \cdot$$

$$\left\{ 1 - \left[\frac{1}{2\,\pi\,h\,t}\right] + 1.3\,\left[\frac{1}{2\,\pi\,h\,t}\right]^2 - 1.3.5\,\left[\frac{1}{2\,\pi\,h\,t}\right]^3 \cdot + \;\ldots\ldots \right\} \qquad (\mathbf{d_1})$$

This expansion, although it does not formally satisfy the original integral equation of the problem is a true asymptotic solution, and may be used for numerical computation with an error less than the last term included. Its convenience for large values of the argument is obvious, and it shows by mere inspection that $V\,(t)$ ultimately approaches zero in accordance with the law $\dfrac{1}{\pi\,\sqrt{h\,t}}$.

Heavisides operational solution is arrived at as follows: If we go back to the original differential equations of the problem and replace $\frac{d}{dt}$ by p, we get the symbolic formula

$$V = \frac{\sqrt{\frac{R}{C\,p}}}{\sqrt{\frac{R}{C\,p} + \frac{1}{C_0\,p}}}$$

Rearranging and introducing the symbol

$$\sqrt{h} = \frac{1}{C_0}\sqrt{\frac{C}{\pi R}}$$

this may be written

$$V = \frac{\sqrt{\frac{p}{\pi h}}}{1 + \sqrt{\frac{p}{\pi h}}} = \sqrt{\frac{p}{\pi h}}\left(1 + \sqrt{\frac{p}{\pi h}}\right)^{-1}$$

Expanding by the Binomial theorem and rearranging we have symbolically

$$V = \left\{1 + \frac{p}{\pi h} + \left(\frac{p}{\pi h}\right)^2 + \dots\right\}\sqrt{\frac{p}{\pi h}}$$
$$- \left\{\frac{p}{\pi h} + \left(\frac{p}{\pi h}\right)^2 + \dots\right\}$$

This equation, as it stands is quite without meaning. Nevertheless Heaviside deduces the correct asymptotic solution of the problem from the symbolic formula by the following empirical rule: Discard all integral powers of the operator p, identify $\sqrt{p}$ as $\frac{1}{\sqrt{\pi t}}$ and replace any p^k in the first bracketted series by $\frac{d^k}{dt^k}$; then,

$$V(t) = \left\{1 + \frac{1}{\pi h}\frac{d}{dt} + \frac{1}{(\pi h)^2}\frac{d^2}{dt^2} + \dots\right\}\frac{1}{\pi\sqrt{h\,t}}$$

$$= \frac{1}{\pi \sqrt{h\,t}} \left\{ 1 - \left(\frac{1}{2\,\pi\,h\,t} \right) + 1.3 \left(\frac{1}{2\,\pi\,h\,t} \right)^2 - \ldots \right\}$$

which agrees with the asymptotic expansion derived above.

Compared with the foregoing operational solution, the asymptotic expansion from the integral equation of the problem may appear cumbersome and involved, and it must be admitted that it entirely lacks the extraordinary directness and simplicity of the Heaviside solution. On the other hand there is this to be said for the solution from the integral equation; it is rigorous and demonstrably correct, whereas Heaviside's remarkable method was as he professes, the outcome of experiment and still lacks the logical demonstration which we are accustomed to require of our mathematical solutions. Again it must be remembered that the chief difficulty lies not so much in deriving as in subsequently computing and interpreting the solution. From this standpoint a series solution leaves much to be desired since its behavior and significance can be arrived at only by direct numerical computation. When, however, the solution is defined by an integral equation, we can not only always derive the formal series solution, and the asymptotic expansion (where such exists), but a study of the integral equation as it stands in many cases gives an insight into the behavior of the function without computation. Furthermore its numerical computation is usually far less laborious than is the computation of the equivalent series solution.

As a final example of the derivation of the asymptotic expansion from the integral equation of the problem we shall require the current at distance x from the sending end of the cable considered above. By formulas **(11)** and **(57)** the required current $I\,(t)$ is given by

$$\sqrt{\frac{C}{\pi R}}\; \frac{d}{dt} \int_0^t d\,\lambda \cdot V\,(t - \lambda) \cdot \frac{\epsilon^{-a/\lambda}}{\sqrt{\lambda}}$$

where $V\,(t)$ is defined by equation $(\mathbf{a}_1)$ and $a = \dfrac{R\,C\,x^2}{4}$

Consequently, as may be shown without any trouble, the integral equation which defines the required current is

$$I(t) = C_0 \sqrt{h}\,\frac{\epsilon^{-a/t}}{\sqrt{t}} - \sqrt{h}\int_0^t d\lambda\,\frac{I(\lambda)}{\sqrt{t-\lambda}} \tag{$\mathbf{a_2}$}$$

where, as above, $\sqrt{h} = \frac{1}{C_0}\sqrt{\frac{C}{\pi R}}$

Multiplying this equation (to argument λ) by $\frac{1}{\sqrt{t-\lambda}}$, integrating with respect to λ from *o* to *t*, and applying Dirichlet's formula, we get:—

$$\int_0^t d\lambda \cdot \frac{I(\lambda)}{\sqrt{t-\lambda}} = C_0\sqrt{h}\int_0^t d\lambda\,\frac{\epsilon^{-a/\lambda}}{\sqrt{t\lambda-\lambda^2}} - \pi\sqrt{h}\int_0^t I(\lambda)\cdot d\lambda \tag{$\mathbf{b_2}$}$$

and finally, from ($\mathbf{a_2}$) and ($\mathbf{b_2}$),

$$I(t) - \pi h\int_0^t I(\lambda)\cdot d\lambda = C_0\sqrt{h}\,\frac{\epsilon^{-a/t}}{\sqrt{t}} - C_0 h\int_0^t d\lambda\,\frac{\epsilon^{-a/\lambda}}{\sqrt{t\lambda-\lambda^2}} \tag{$\mathbf{c_2}$}$$

But

$$\int_0^t d\lambda\,\frac{\epsilon^{-a/\lambda}}{\sqrt{t\lambda-\lambda^2}} = \sqrt{a\pi}\int_0^t d\lambda\cdot\frac{\epsilon^{-a/\lambda}}{\lambda^{3/2}}$$

$$= \pi - 2\sqrt{\frac{a\pi}{t}}\left\{1 - \frac{1}{3\cdot 1!}\left(\frac{a}{t}\right) + \frac{1}{5.2!}\left(\frac{a}{t}\right)^2 + \dots\right\} \tag{$\mathbf{d_2}$}$$

and

$$\frac{\epsilon^{-a/t}}{\sqrt{t}} = \frac{1}{\sqrt{t}}\left\{1 - \frac{1}{1!}\left(\frac{a}{t}\right) + \frac{1}{2!}\left(\frac{a}{t}\right)^2 \dots\dots\right\} \tag{$\mathbf{e_2}$}$$

Substitution of $(\mathbf{d}_2)$ and $(\mathbf{e}_2)$ in $(\mathbf{c}_2)$ and rearrangement gives

$$\pi h \int_0^t I(\lambda)\cdot d\lambda - I(t) = \pi h C_0$$

$$- C_0 \sqrt{\frac{h}{t}} \left\{ \begin{array}{l} \qquad\quad \left(1+\frac{2}{1}\sqrt{a h \pi}\right) \\ -\frac{1}{1\,!}\left(\frac{a}{t}\right)\left(1+\frac{2}{3}\sqrt{a h \pi}\right) \\ +\frac{1}{2\,!}\left(\frac{a}{t}\right)^2\left(1+\frac{2}{5}\sqrt{a h \pi}\right) \\ -\frac{1}{3\,!}\left(\frac{a}{t}\right)^3\left(1+\frac{2}{7}\sqrt{a h \pi}\right) \\ \quad \cdots\cdots \end{array}\right. \qquad (\mathbf{f}_2)$$

The asymptotic expansion of this equation can now be derived without any difficulty; as the expression becomes somewhat complicated we shall not however, carry out the solution in detail. From the equation, as it stands, it is clear that the total charge passing any point x is simply C_0 and that $I(t)$ ultimately becomes

$$\frac{1}{2\pi}\,\frac{C_0}{t\sqrt{h\,t}}\ (1+2\sqrt{a h \pi})$$

To enter upon more advanced applications of the synthetic method is beyond the scope of the present paper. The simple examples dealt with above, will, it is hoped, serve to indicate the appropriate treatment and the wide range of problems to which the method is applicable.

NOTE 1

Owing to the very great importance of mono-periodic currents, the formulas appropriate to the sinusoidal e.m.f. sin $(p\,t+\theta)$ have been the subject of particular study. While formula (**12**) is fundamental and its evaluation by aid of the harmonic analyzer is usually indicated, the derived formulas given below are of value in particular cases, especially when a knowledge of the behavior of the system to very low or very high frequencies is required.

If the cosine and sine functions in the intergrand of formula (**12**) are expanded in the usual convergent power series, it is easy to show that we get by repeated partial integrations and some easy simplifications

$$I = \sin\theta . \quad u(t) + \cos\theta \cdot v(t) \qquad \text{(a)}$$

where

$$u(t) = A(t) - p^2 \int_0^t \int_0^\lambda A(\lambda_1) \cdot d\lambda \, d\lambda_1$$

$$+ p^4 \int_0^t \int_0^\lambda \int_0^{\lambda_1} \int_0^{\lambda_2} A(\lambda_3) \, d\lambda \, d\lambda_1 \, d\lambda_2 \, d\lambda_3 \qquad \text{(b)}$$

$$-p^6 \int_0^t \ldots \int_0^{\lambda^4} A(\lambda_5) d\lambda \ldots d\lambda_5$$

$$\ldots\ldots$$

and

$$v(t) = p \int_0^t A(\lambda) \, d\lambda - p^3 \int_0^t \int_0^\lambda \int_0^{\lambda_1} A(\lambda_2) d\lambda \, d\lambda_1 \, d\lambda_2$$

$$+ p^5 \int_0^t \ldots \int_0^{\lambda_3} A(\lambda_4) \, d\lambda \ldots d\lambda_4 \qquad \text{(c)}$$

$$- p^7 \int_0^t \ldots \int_0^{\lambda_5} A(\lambda_6) \, d\lambda \ldots\ldots d\lambda_6$$

$$\ldots\ldots$$

Both of these series are absolutely convergent for all values of p, but their direct computation is practicable only for relatively small values of p. In the limit $p = 0$, $u(t)$ reduces to $A(t)$ and $v(t)$ to zero as we should expect.

The functions $u(t)$ and $v(t)$ are obviously connected by the relation,

$$v(t) = p \int_0^t u(\lambda) \, . \, d\lambda \qquad \text{(d)}$$

so that $v(t)$ is calculable from $u(t)$ by mechanical integration.

Furthermore it is easy to show from formula (**b**) that $u(t)$ satisfies the integral equation

$$u(t) = A(t) - p^2 \int_0^t \int_0^\lambda u(\lambda_1) \, . \, d\lambda \, d\lambda_1$$

which can be written (by reversing the order of integration of the multiple integral)

$$u(t) = A(t) - p^2 \int_0^t (t - \lambda) \, . \, u(\lambda) \, . \, d\lambda \qquad \text{(e)}$$

The integral equation is now in canonical form, and in some problems its numerical integration is simpler than the mechanical evaluation of formula (**12**). For a brief account of integral equations and the methods for their formal and numerical solution, see Note 3.

The foregoing formulas are often useful when we wish to investigate the behavior of the system to applied voltages of low frequency; when, on the other hand, the applied frequency is high the following formula is applicable and is of considerable value in interpreting the ultimate character of the *transient distortion:*

If the applied voltage be $\sin (p t + \theta)$ *and if* p *be greater than* (p_m) *where* p_m *is the greatest root of the determinantal equation* $Z(p) = 0$, *then the transient distortion, as defined by formula* (**14**), *is formulated by the convergent series:*

$$\cos \theta \,.\, g(t) + \sin \theta \,.\, h(t)$$

where

$$g(t) = \frac{1}{p} A^{(1)}(t) - \frac{1}{p^3} A^{(3)}(t) + \frac{1}{p^5} A^{(5)}(t) \ldots .$$

$$h(t) = \frac{1}{p^2} A^{(2)}(t) - \frac{1}{p^4} A^{(4)}(t) + \frac{1}{p^6} A^{(6)}(t) \ldots .$$

and

$$A^{(n)}(t) = \frac{d^n}{dt^n} A(t)$$

The proof of this last formula and the sufficient condition for its convergence are easily established. If the frequency is very high it is clear that the transient distortion becomes ultimately,

$$\frac{1}{p} A'(t)$$

and therefore, if the frequency be high enough the *transient distortion in all systems is inversely proportional to the applied frequency*, provided that the characteristic oscillation frequencies have a finite upper limit. Furthermore, even when divergent, series of the above form, in many cases, constitute asymptotic expansions which are valid for numerical computation.

NOTE 2

From our restricted standpoint an asymptotic expansion is defined as an expansion of a function in inverse powers of the argument. The theory of asymptotic expansions occupies an important place in modern analysis. With the questions of divergence, convergence and summability to which pure analysis is largely restricted, we are not concerned, but rather with methods of asymptotic expansions, regarding which knowledge is quite fragmentary. For a good brief discussion of asymptotic expansions from the point of view of analysis, the reader is referred to Whittaker and Watson—"A Course in Modern Analysis," Chap. VIII.

When the system under consideration consists of a finite number of branches or meshes, the asymptotic expansion of the function of $\frac{1}{Z(p)}$ is always possible. A general rule for the expansion is as follows: Replace p by $\frac{1}{y}$ in $\frac{1}{Z(p)}$ and write

$$\frac{1}{Z(p)} = \frac{1}{Z\left(\frac{1}{y}\right)} = \varphi(y)$$

Then expand $\varphi(y)$ in the usual Taylor's series

$$\varphi(y) = \varphi(o) + \varphi'(o) \cdot \frac{y}{1!} + \varphi''(o) \cdot \frac{y^2}{2!}$$

$$= \Sigma\, \varphi^m(o) \cdot \frac{y^m}{m!}$$

Then the required asymptotic expansion is given by

$$\frac{1}{Z(p)} \sim \Sigma\, \varphi^m(o) \cdot \frac{1}{m!\, p^m}$$

In many problems, however, much shorter ways of expanding suggest themselves, and often the binomial expansion can be directly applied.

NOTE 3

In this connection the writer takes the opportunity of calling attention to a formula, as yet unpublished, which was derived by Mr. T. C. Fry of the Western Electric Company in Nov. 1916. Starting with the Fourier integral which formulates the current in response to an applied voltage $f(t)$ and applying a theorem of Hermites' thereto, Mr. Fry arrived at the original formula (adopting the notation of the present paper)

$$I = \int_0^t f(\lambda)\, d\lambda \,.\, \Sigma \frac{\epsilon^{p_m(t-\lambda)}}{Z'(p_m)}$$

Mr. Fry restricted consideration to systems for which $\frac{1}{Z(\infty)} = A(o) = o$; for this case it is equivalent to formula (**10**) of this paper.

The writer has derived the power series solution from the Fourier integral formulation by asymptotically expanding $\frac{1}{Z(p)}$ in the integrand and then evaluating the infinite integrals by the calculus of residues.

Since this paper was written the author has been privileged to see some more recent work, as yet unpublished, of Mr. Fry's, in which he has secured results of great originality and value by attacking the Fourier integral by the methods of advanced analysis.

NOTE 4

The integral equation, known as Fredholm's equation is of the following form

$$v(t) = f(t) + \int_b^a v(\lambda) \cdot u(t, \lambda) \cdot d\lambda$$

where $f(t)$ and $u(t, \lambda)$ are known functions. The type of integral equation with which we are concerned is less general in form:

$$v(t) = f(t) + \int_0^t v(\lambda) \cdot u(t - \lambda) \cdot d\lambda \qquad \textbf{(a)}$$

differing from the general equation in that the upper limit of integration is variable and in that the kernel or nucleus of the equation is a function of $t - \lambda$ instead of being a perfectly arbitrary function of t and λ. When the upper limit of integration is variable the equation is usually called Voltenra's equation in honor of the Italian mathematician who has studied it extensively.

The formal solution of this equation is gotten by successive or repeated substitution of the right hand side of the equation for $v\ (t)$ in the integral. It is

$$
\begin{aligned}
v\,(t) = f\,(t) &+ \int_0^t u\,(t-\lambda)\cdot f\,(\lambda)\cdot d\,\lambda \\
&+ \int_0^t u\,(t-\lambda)\cdot \int_0^\lambda u\,(\lambda-\lambda_1)\cdot f\,(\lambda_1)\cdot d\,\lambda\, d\,\lambda_1 \\
&+ \int_0^t u\,(t-\lambda)\int_0^\lambda u\,(\lambda-\lambda_1)\int_0^{\lambda_1} u\,(\lambda_1-\lambda_2) \\
&\qquad\qquad f\,(\lambda_2)\,d\,\lambda\;\;d\,\lambda_1\;\;d\,\lambda_2 \\
&+ \dots
\end{aligned}
$$

Pure analysis is concerned, of course, not with the numerical interpretation of this solution but with questions as to the uniqueness, convergence, etc. and it has been shown that the solution is not only unique but absolutely convergent.

Except, however, for very simple forms of the functions $f\ (t)$ and $u\ (t)$ the formal solution given above is quite useless for our purpose, which must always be to arrive at interpretable and computable results. Indeed our conception of a solution is quite distinct from that of pure analysis, and our tests must always be pragmatic.

If neither $f\ (t)$ or $u\ (t)$ involve fractional powers of t the *power series solution* can be gotten from (a) by repeated differentiations as follows:

From (a) we have:

$$v\,(o) = f\,(o)$$

$$
\begin{aligned}
v'\,(t) = \frac{d}{d\,t}\,v\,(t) = f'\,(t) + u\,(o)\cdot f\,(t) + \int_0^t v\,(\lambda) \\
\cdot\, u'\,(t-\lambda)\cdot d\,\lambda
\end{aligned}
$$

$$v'\,(o) = f'\,(o) + u\,(o)\cdot v\,(o)$$

Proceeding with repeated differentiations we get

$$
\begin{aligned}
&v''\,(o) = f''\,(o) + u\,(o)\cdot v'\,(o) + u'\,(o)\cdot v\,(o) \\
&v'''\,(o) = f'''\,(o) + u\,(o)\cdot v''\,(o) + u'\,(o)\cdot v'\,(o) + u''\,(o) \\
&\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\cdot\, v\,(o)
\end{aligned}
$$

Hence $v\ (o)$, $v'\ (o)$, $v''\ (o) \dots v^{(m)}\ (o)$ are all expressible in terms of $f\ (t)$ and $u\ (t)$ and their derivatives. Hence the solution is

$$v(t) = v(o) + v'(o) \cdot \frac{t}{1!} + v''(o) \cdot \frac{t^2}{2!} + -$$

$$= \Sigma\, v^{(m)}(o) \cdot \frac{t^m}{m!}$$

where $v^m(o)$ is gotten from (*b*).

If either $u(t)$ or $f(t)$ contains fractional powers of t, the solution can be gotten by *assuming* a series solution of the form

$$v(t) = \Sigma\, a_m t^m + \sqrt{t}\, \Sigma\, b_m t^m$$

substituting in the integral equation, integrating and then determining the unknown coefficients of the series solution by direct equation of like powers of t.

Corresponding to every series solution of the form

$$\Sigma\, a_m t_m + \sqrt{t}\, \Sigma\, b_m t^m$$

Heaviside, by his operational treatment, arrives at an asymptotic solution of the form

$$\Sigma \frac{c_m}{t^m} + \frac{1}{\sqrt{t}} \Sigma \frac{d_m}{t^m}$$

which, although divergent, may be used for computation, in spite of the fact, which may be easily proved, that the latter series does not satisfy the integral equation and is therefore not a formal solution of the problem. We shall show later that the asymptotic solutions are derivable from the integral equations of the problem, and thus verify Heaviside's remarkable results.

The numerical integration of the integral equation (**a**) is carried out as follows: We remark that the integral appearing in (**a**) is the limit of the summation:

$$\begin{aligned}
&[v(o) \cdot u(t) + v(\Delta t) \cdot u(t - \Delta t)]\, \Delta t/2 \\
&+ [v(\Delta t) \cdot u(t - \Delta t) + v(2\Delta t) \cdot u(t - 2\Delta t)] \\
&\qquad\qquad\qquad\qquad\qquad\qquad \Delta t/2 \\
&+ \dots \\
&+ [v(t - \Delta t) \cdot u(\Delta t) + v(t) \cdot u(o)] \cdot \Delta t/2 \\
&= v(o) \cdot u(t) \cdot + v(t) \cdot u(o) \Delta t/2 \\
&+ \Delta t \sum_{1}^{n-1}{}_{m}\; v(m\Delta t) \cdot u(t - m\Delta t)
\end{aligned}$$

When $t = n \Delta t$

Equation (a) then is the *limit* of the expression

$$\left[1 - u(o) \cdot \frac{\Delta t}{2} \right] v(t) = f(t) + v(o) \cdot u(t) \cdot \frac{\Delta t}{2}$$

$$+ \Delta t \sum_{1}^{n-1}{}_{m} \; v(m \Delta t) \cdot u(t - m \Delta t)$$

When $n \Delta t = t$.
or

$$v(t) = \frac{1}{1 - u(o) \cdot \frac{\Delta t}{2}} \left\{ \begin{array}{l} f(t) + f(o) \cdot \frac{\Delta t}{2} \cdot u(t) \\ + \Delta (t) \sum_{1}^{n-1}{}_{m} v(m \Delta t) \cdot u(t - m \Delta t) \end{array} \right.$$

If we now call $t = t_1$; $2 t = t_2$; . . .
$n \Delta t = t_n$ we have:—
$v(o) = f(o)$

$$v(t_1) = \frac{1}{1 - u(o) \cdot \frac{\Delta t}{2}} \left\{ f(t_1) + f(o) \cdot u(t_1) \cdot \frac{\Delta t}{2} \right.$$

$$v(t_2) = \frac{1}{1 - u(o) \cdot \frac{\Delta t}{2}} \left\{ \begin{array}{l} f(t_2) + f(o) \cdot u(t_2) \cdot \frac{\Delta t}{2} \\ \quad + v(t_1) \cdot u(t_1) \cdot \Delta t \end{array} \right.$$

$$v(t_3) = \frac{1}{1 - u(o) \cdot \frac{\Delta t}{2}} \left\{ \begin{array}{l} f(t_3) + f(o) \cdot u(t_3) \cdot \frac{\Delta t}{2} \\ + \Delta t \, \{ v(t_1) \cdot u(t_2) + v(t_2) \cdot u(t_1) \} \end{array} \right\}$$

. . . . .

In each of these equations the factors appearing on the right hand side are known from the preceding equations, and we thus can compute $v(t)$ for any required value of t.

The time element Δt should be chosen with reference to the character of the known function involved in the integral equation; that is, it should be so small as to make the curvature, or second differences of these functions small within the interval Δt. The precision of this method increases, of course, as the time interval Δt is diminished and can be made as exact as we please by taking Δt sufficiently small.

The method has been tried out pretty thoroughly in a series of problems and works well with a precision quite sufficient for practical purposes. The labor is very much less than that involved in a computation of a power series solution; and the accuracy of the results is readily checked.

NOTE 5

The steady-state properties and characteristics of periodic structures (of which the artificial line is a particular case) were investigated by Dr. G. A. Campbell, Research Engineer of the American Telephone and Telegraph Company, who discovered their extremely interesting and important action as "wave-filters," due to their property of transmitting with small attenuation steady-state currents of all frequencies lying within a continuous range or ranges of frequency (which may be termed transmission bands) while sharply attenuating all currents of frequencies outside these transmission bands. For a fairly full account of the wave filter and its theory, see U. S. patent No. 1,227,113 to G. A. Campbell.

NOTE 6

The Bessel function of the first kind, $J_n(Z)$ and $I_n(Z)$ are defined, when n is a positive integer, by the absolutely convergent series:

$$J_n(Z) = \left(\frac{Z^n}{2^n \cdot n\,!}\right) \cdot \left\{ 1 - \frac{Z^2}{2\,(2n+2)} + \frac{Z^4}{2.4\,(2n+2)\,(2n+4)} + \dots - \frac{Z^6}{2.4.6\,(2n+2)\,(2n+4)\,(2n+6)} - + \dots \right.$$

$$I_n(Z) = i^{-n} J_n(i\,Z)$$

$$= \left(\frac{Z^n}{2^n \cdot n\,!}\right) \cdot \left\{ 1 + \frac{Z^2}{2\,(2n+2)} + \frac{Z^4}{2.4\,(2n+2)\,(2n+4)} + \frac{Z^6}{2.4.6\,(2n+2)\,(2n+4)\,(2n+6)} + \dots \right.$$

The terms of $J_n\,(Z)$ are alternating in sign while those of $I_n\,(Z)$ are all positive.

For values of Z very large compared with n, the functions can be computed from the asymptotic formulas:

$$J_n\,(Z) = \sqrt{\frac{2}{\pi Z}}\left\{ P_n \,.\cos\left(\frac{2\,n+1}{4}\,\pi - Z\right) + Q_n \,.\sin\left(\frac{2\,n+1}{4}\,\pi - Z\right)\right\}.$$

where

$$P_n = 1 - \frac{(4\,n^2-1)\,(4\,n^2-9)}{2\,!\,(8\,Z)^2} + \frac{(4\,n^2-1)\,(4\,n^2-9)\,(4\,n^2-25)\,(4\,n^2-49)}{4\,!\,(8\,Z)^4}\ldots$$

$$Q_n = \frac{4\,n^2-1}{8\,Z} - \frac{(4\,n^2-1)\,(4\,n^2-9)\,(4\,n^2-25)}{3\,!\,(8\,Z)^3}\,.$$

and

$$I_n\,(Z) = \frac{\epsilon^Z}{\sqrt{2\,\pi\,Z}}\left\{1 - \frac{4\,n^2-1}{1\,!\,.\,2^3\,Z} + \frac{(4\,n^2-1)\,(4\,n^2-9)}{2\,!\,.\,2^6\,.\,Z^2}\ldots\right.$$

For the large order of functions with which we are mainly concerned these asymptotic expansions are useless for values of argument of practical importance, since we are concerned with the behavior of the functions in the neighborhood of $Z = n$. The computation of the functions is carried out without much difficulty from the valuable asymptotic formulas given by J. W. Nicholson in a series of papers appearing in the *Philosophical Magazine* (Dec. 1907, August 1908, July 1909, Feb. and Dec. 1910). These formulas are too long to reproduce here and the original papers should be consulted.

The properties of the integral function $\int_0^Z J_n\,(Z_1)\,d\,z_1$, are of course determined by the corresponding properties of the Bessel function appearing in the integrand; it does not appear, however, that the integral function has been the subject of any extensive study in spite of its extremely interesting properties. A few of these properties which are of importance for our purposes are:

(1) $\int_0^\infty J_n(z)\,dz = 1$ for all values of n.

(2) For values of z very large compared with n,

$$\int_0^Z J_n(z_1)\,dz_1 \sim 1$$

$$-\sqrt{\frac{2}{\pi}}\int_t^\infty \cos\left(z_1 - \frac{2n+1}{4}\pi\right)\frac{dz_1}{\sqrt{z_1}}$$

the integral term of which can be resolved into Fresnel integrals.

(3) For large values of n, the function $\int_0^Z J_n(z_1)\,dz_1$ is insignificant for values of Z less than n. From a mathematical standpoint, this property explains the virtual velocity of propagation of the artificial line.

(4) $$\text{Limit } n \to \infty \left[\int_0^{\lambda n} J_n(z_1)\,dz_1\right] \begin{array}{ll} = o, & \lambda < n \\ = 1, & \lambda > n \end{array}$$

This relation enables us to derive the solution for the smooth line as the limiting case of the artificial line, as the aggregate value of the constant is kept finite and the number of sections approaches infinity.

NOTE 7

The correctness of the solution formulated by (**35**) may be verified by deriving the corresponding steady-state formula by aid of equation (**13**). If a voltage $\sin(pt+\theta)$ is applied at midload position to an infinitely long periodically loaded cable the steady-state or periodic current in the *qth* load-coil is given by substitution of (**35**) in (**13**); it is

$$\sqrt{\frac{C}{L}}\left\{\begin{array}{l} \sin(pt+\theta)\displaystyle\int_0^\infty \cos(w\lambda)\cdot J_{2q}(\lambda)\cdot d\lambda \\ -\cos(pt+\theta)\displaystyle\int_0^\infty \sin(w\lambda)\cdot J_{2q}(\lambda)\cdot d\lambda \end{array}\right.$$

When $w = \frac{p}{p_c} = \frac{p}{2v} = \frac{p}{2}\sqrt{LC}$

p_c indicates $2\pi f_c$ where f_c is the "critical or cut-off frequency of the line.

The infinite integrals have been evaluated, they are (see Nielsen—*Handbuch der Cylinderfunctionen*, p. 195.)

$$\int_0^\infty \cos(w\lambda)\cdot J_{2q}(\lambda)\cdot d\lambda = \frac{\cos(2q\sin^{-1}w)}{\sqrt{1-w^2}} \qquad w < 1$$

$$= -\frac{\sin q\pi}{\sqrt{w^2-1}}\left(w-\sqrt{w^2-1}\right)^{2q} \qquad w > 1$$

$$\int_0^\infty \sin(w\lambda)\cdot J_{2q}(\lambda)\cdot d\lambda = \frac{\sin(2q\sin^{-1}w)}{\sqrt{1-w^2}} \qquad w < 1$$

$$= \frac{\cos q\pi}{\sqrt{w^2-1}}\left(w-\sqrt{w^2-1}\right)^{2q} \quad w > 1$$

Hence, if $w < 1$, $p < p_c$, the frequency is less than the critical frequency and

$$|I_q| = \sqrt{\frac{C}{L}}\,\frac{1}{\sqrt{1-w^2}}$$

If $w > 1$ the frequency is above the critical frequency and

$$|I_q| = \sqrt{\frac{C}{L}}\,\frac{1}{\sqrt{w^2-1}}\left(\frac{1}{w+\sqrt{w^2-1}}\right)^{2q}$$

which agree exactly with the results gotten by the usual steady state or periodic theory, and show the critical character of the frequency $\frac{p_c}{2\pi}$.

NOTE 8

From formulas (**12**) and (**53**) we can arrive at some important deductions regarding the relations obtaining between the frequency of the applied voltage and the character of the transient distortion on the smooth line.

If the applied e.m.f. is taken as $\sin(pt+\theta)$ (applied at

$t = o$ and $x = o$), the current at point x on the line is by (**12**) and (**53**)

$$I_x = 0 \qquad \text{for } v\,t < x$$

$$\begin{aligned} I_x = \quad & \sqrt{\frac{C}{L}}\, \epsilon^{-ax} \sin\left(p \left[t - \frac{x}{v} \right] + \theta \right) \\ & + \sqrt{\frac{C}{L}}\, \epsilon^{-ax} \left\{ \begin{aligned} & \sin(p\,t + \theta) \int_x^{vt} \cos\left[\frac{p}{v}\,\lambda \right] \frac{d}{d\,\lambda}\,\varphi(\lambda)\,d\,\lambda \\ & - \cos(p\,t + \theta) \int_0^{vt} \sin\left[\frac{p}{v}\,\lambda \right] \frac{d}{d\,\lambda}\,\varphi(\lambda)\,d\,\lambda \end{aligned} \right. \end{aligned}$$

where

$$\varphi(\lambda) = \epsilon^{-a(\lambda - x)}\, I_0\left(a \sqrt{\lambda^2 - x^2}\right)$$

Inspection of this formula shows that the first term is the final steady state provided the frequency of the applied voltage is high enough to justify the employment of the usual approximate formulas for the steady-state characteristic impedance and propagation factor. The integral terms represent transient distortion. To a first order of approximation the integral terms are of an order of magnitude

$$\frac{1}{p} \cdot \frac{R}{2\,L} \cdot (a\,x - 2)$$

provided $a\,x > 2$.

The building up of the current wave to its final steady state value may therefore be described as follows:

If a voltage of frequency f is applied to a smooth transmission line the current at distance x out on the line is identically zero for a time interval x/v after the application of the voltage; at the end of this time interval it has an instantaneous jump to its final steady state value, but is thereafter subjected to a transient distortion the magnitude of which is roughly *inversely proportional to the applied frequency,* and the sensible duration of which diminishes with the applied frequency. The transient distortion is negligibly small for $a\,x < 2$, while for large values of $a\,x$ it increases rapidly at a more than linear rate with the product $R/L\,a\,x$. If the applied frequency is made indefinitely great the transient distortion approaches zero both in magnitude and duration.

From formulas (**15**) and (**53**) the complete wave solution for the leakageless line of length s, short-circuited at $x = s$, and actuated by a unit voltage applied at $x = o$ and $t = o$, is

$$A_x(t) = \sqrt{\frac{C}{L}}\,\epsilon^{-\rho t}\cdot$$
$$\left\{\begin{aligned} & I_0\left(\rho\sqrt{t^2-\left[\frac{x}{v}\right]^2}\right) \\ & \qquad + 2\sum_{1}^{\infty}{}_{m}\, I_0\left(\rho\sqrt{t^2-\left[\frac{2\,m\,s+x}{v}\right]^2}\right) \\ & \qquad + 2\sum_{1}^{\infty}{}_{m}\, I_0\left(\rho\sqrt{t^2-\left[\frac{2\,m\,s-x}{v}\right]^2}\right) \end{aligned}\right. \qquad (\mathbf{a})$$

This solution will be discussed with particular reference to the velocity of transmission regarding which there seems to exist considerable confusion of thought or at any rate looseness of statement. The case of the leakageless line is chosen purely for the sake of simplicity and the following remarks apply also to the general case when leakage is present.

Now in the light of the derivation of formula (**53**) it is to be understood that the terms of formula (**a**) come into existence not at time $t = o$ but *only as the arguments of the* I_0 *functions pass from imaginary to real values.* That is, while all the terms are written down in formula (**a**), they come into existence at successive intervals of time.

Thus for $o < t < x/v$, $A_x(t)$ is identically zero, and at $t = x/v$ the direct wave (which alone exists on the infinitely long line) arrives at x, and it alone exists there until $t = \dfrac{2\,s - x}{v}$ when the first reflected wave arrives. At a subsequent time $t = \dfrac{2\,s + x}{v}$ the second reflected wave arrives and so the final steady state is built up. Analytically,

$$A_x(t) = 0 : \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 0 < t < x/v$$

$$A_x(t) = \sqrt{\frac{C'}{L}}\, \epsilon^{-\rho t}\, I_0 \left\{ \rho \sqrt{t^2 - \left(\frac{x}{v}\right)^2} \right\} \dots\dots\dots\dots$$

$$x/v < t < \frac{2s - x}{v}$$

$$A_x(t) = \sqrt{\frac{C}{L}}\, \epsilon^{-\rho t} \left\{ I_0 \left(\rho \sqrt{t^2 - \left[\frac{x}{v}\right]^2} \right) \right.$$

$$\left. + 2 I_0 \left(\rho \sqrt{t^2 - \left[\frac{2s - x}{v}\right]^2} \right) \right. \frac{2s - x}{v} . < t < \frac{2s + x}{v}$$

$$\dots\dots$$

Not until $t = \infty$ do all the terms finally come into existence.

Now the outstanding deduction from this interpretation of formula (**a**) is that it represents a series of waves which are propagated with finite velocity $x = \frac{1}{\sqrt{L C}}$ which is independent of the dissipation occurring during transmission whether due to line resistance or leakage. Consequently formula (**a**) is the wave solution; the first term represents the direct wave, which alone exists on the infinitely long line; the second summation represents a series of secondary waves reflected at $x = s$ and the first summation a series of secondary waves reflected at $x = o$. Each wave is represented by the product of an exponential term and a Bessel function, the latter formulating the distortion which the wave suffers during transmission, and which is absent on the non-dissipative or distortionless line. The foregoing discussion of the wave solution holds for all types of applied voltages except that the character of the distortion of the wave during transmission is modified in accordance with formula (**11**). It is also applicable to all types of terminal arrangements, due regard being had to the fact that the form of the reflected waves is modified by the character of the terminal apparatus. In no case, however, is the velocity of transmission of the series of waves modified by the type of applied voltage or character of the end terminations.

Now in accordance with the method of derivation of formula (**a**) it must be equivalent to the expansion (**40**) (setting $G = o$) and this expansion will accordingly be investigated. After easy simplification formula (**40**) with G put equal to zero may be written,

$$A_x(t) = 2\sqrt{\frac{C}{L}}\,\epsilon^{-\rho t}\cdot\sum_{1}^{\infty}{}_m \frac{\cos\left(m\cdot\frac{x\pi}{s}\right)}{s\sqrt{\left(m\frac{\pi}{s}\right)^2-\left(\frac{\rho}{v}\right)^2}}$$

$$\cdot\sin\left(v\sqrt{\left(m\frac{\pi}{S}\right)^2-\left(\frac{\rho}{v}\right)^2}\,t\right)+\frac{1}{Rs}\left(1-\epsilon^{-\frac{R}{L}t}\right) \qquad (\mathbf{b})$$

$$= \sqrt{\frac{C}{L}}\,\epsilon^{-\rho t}\,\Sigma_m$$

$$\left\{\begin{aligned}&\sin\left(m\frac{v\pi}{s}\sqrt{1-h^2_m}\left(t-\frac{x}{v\sqrt{1-h^2_m}}\right)\right)\\&+\sin\left(m\frac{v\pi}{s}\sqrt{1-h^2_m}\left(t+\frac{x}{v\sqrt{1-h^2_m}}\right)\right)\end{aligned}\right\}$$

$$\frac{1}{\pi m\sqrt{1-h^2_m}}+\frac{1}{R\,s}\left(1-\epsilon^{-\frac{R}{L}t}\right) \qquad (\mathbf{c})$$

where $h_m = \dfrac{1}{m}\,\dfrac{\rho\,s}{\pi\,v}$

This type of solution is often referred to or regarded as a wave solution; in fact, however, it is a formulation in terms of normal or characteristic *vibrations* and in a more precise terminology is a normal function or vibrational solution. Each term of (**b**) is the product of a cosine function of space and a sine function of time which may be thrown into the form of (**c**) in which the individual terms appear to represent propagated waves. The propagation is only apparent, however, since each term of (**c**) is instantaneously produced on the spot at $t = o$ and is not *propagated* as are the component waves of the wave solution (**a**). The instantaneously produced terms of (**c**), however, combine for a definite time x/v to annul each other so that the summation is identically zero until $t = \dfrac{x}{v}$

the solution is therefore mathematically correct but physically artificial and deceptive. The most serious confusion of thought results from a tendency to interpret the summation (**c**) from a consideration of a single term and from the prevalent error of regarding the individual characteristic *vibrations* as *propagated waves.* Thus by inspection of (**c**) each term has an *apparent* velocity of phase propagation $v \sqrt{1 - h^2_m}$ whereas the actual velocity of propagation of the wave is identically v. From this viewpoint the velocity of propagation of the vibrations *appears* to increase with the frequency of the vibrations up to the limiting value v. $v \sqrt{1 - h^2_m}$ is merely the *apparent velocity of phase propagation* of the characteristic vibration and only in the case of the non-dissipative and distortionless line (where $h_m = o$) is the apparent velocity of phase propagation equal to v which is the true "speed of propagation of the electric phenomenon in the circuit." The increase of $v \sqrt{1 - h^2_m}$ with the frequency of the characteristic vibration does not indicate an increased speed of propagation with frequency but merely a *change of form* or *distortion* of the wave during transmission.

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ELECTROMAGNETIC THEORY OF THE TELEPHONE RECEIVER

With Special Reference to Motional Impedance

BY A. E. KENNELLY AND H. NUKIYAMA

Abstract of Paper

The theory of the telephone receiver here offered is based upon the motional impedance circle which has been published in various chapters during the last few years. The new theory, which is stated under definite limitations, is a further development; taking into account the m.m.f. produced by the vibration of the diaphragm in the permanent magnetic field. The motional power is thus shown to be derived partly from the testing alternating current and partly from changes in power expended in the magnetic circuit. The motional impedance circle may therefore also be regarded as a power circle, with components along three different axes of reference.

Object of the Paper. It is well known that every telephone receiver possesses a certain difference of vector impedance between the "damped" and "free" conditions, such that, when plotted in polar coordinates, over a suitable range of alternating-current frequency, gives rise to a "motional-impedance locus", which locus is approximately circular, and is known as its "motional-impedance circle".

The motional impedance circle of a telephone receiver affords valuable material for determining the principal mechanical and electrical constants of the instrument.*

In the theory of the motional-impedance circle, as hitherto published, certain phenomena have been left out of consideration for the sake of simplicity; and especially that component of alternating magnetic flux passing through the coils which is due to the displacement of the diaphragm from its zero position when freely vibrating. The result has been that the motional-impedance circle failed to reveal the power expended parasitically (by both hysteresis and eddy currents) in the magnetic circuit. This defect in the theory has already been pointed out by Eccles.†

Manuscript of this paper was received on January 29, 1919.

*Bibliography, No. 9.

†Bibliography, No. 24.

It is the object of this paper to supply the above-mentioned omission, and thus to offer a closer approximation between the theory and the observed behavior of the telephone receiver as an electromagnetic motor. It should be pointed out, however, that the theory here presented is still far from being complete, and that much more work, both theoretical and experimental remains to be executed, analysed and reported, before the theory can be regarded as satisfactorily established.

Limitations of the New Theory. The following limitations should be noted in regard to the stage of attainment aimed at in the theory here presented.

1. The alternating current supplied to the receiver is of small amplitude, and of single frequency; so that the magnetic flux passing through the coils and polar surfaces may be regarded as a normal permanent flux, plus a small sinusoidal variation. All the alternating mechanical, magnetic and electric quantities, are therefore assumed to be simple harmonic functions of the time.
2. Throughout the range of frequency considered, the flux in the magnetic circuit of the coils retains the same magnitude and phase with respect to the constant exciting alternating current. This means that the influences of magnetic skin effect and hysteresis in the magnetic circuit remain substantially constant.
3. The proportional effect of a small increment of m.m.f. in the magnetic circuit, due either to a small increase in exciting current, or to a small diminution in air gap at the poles, shall be the same, both in magnitude and in phase.
4. That over the range of frequencies considered, the "force-factor" A, the "equivalent mass" m of the diaphragm, the "mechanical resistance" r of the same, and the "stiffness coefficient" s, remain substantially constant.

The theory is presented with relation to a series of impedance measurements already published* on a particular bipolar Bell receiver "*C*"; so that these measurements offer, in a particular case, a check upon the application of the theory.

Magnetic Circuit and Vibrating System. In Fig. 1, it is assumed that the two poles N and S are permanently magnetized, as though under the action of a constant-current magnetomotive force $\mathfrak{F}_0$ gilberts. Under the influence of the permanent magnetic flux Φ_0 maxwells in the magnetic circuit, the diaphragm becomes flexed from its horizontal plane position and comes to rest at a certain zero position at the same distance from each pole. Since vibrational displacements occur on each side alternately of this reference position of rest, we may reckon a displacement therefrom of x cm. towards the poles as positive, and away from the poles as negative. The total number of turns on both coils together, is taken as N. The active surface of each pole, or of the diaphragm opposite thereto, is taken as S sq. cm., and since the polar gap is small by comparison with the linear dimensions of this surface, we may neglect the magnetic fringe at the polar edges.

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*Bibliography 17, pp. 422–428 and 449–450.

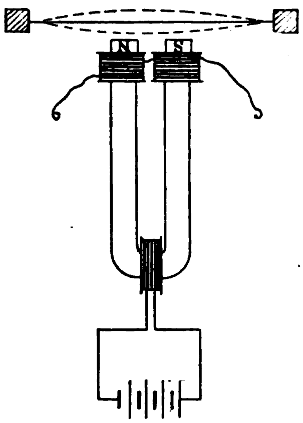

Fig. 1—Simplified Magnetic Circuit of Bipolar Receiver

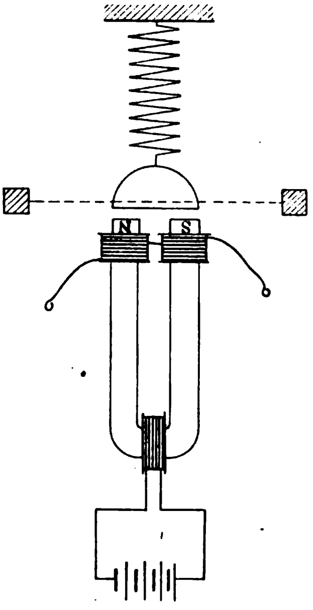

Fig. 2—Simplified Mechanical System of Bipolar Receiver

In Fig. 2, the mechanical vibration system is indicated as simplified into an equivalent mass m grams, under the retractive influence, so far as concerns alternating stresses, of s dynes per cm. of displacement. The frictional resistance force of this system to motion is taken as simply proportional to the velocity of displacement; so that if $\dot{x}$ represents the velocity $\frac{dx}{dt}$ of the mass m, the retarding force is $-r\dot{x}$ dynes, where r is the mechanical resistance of the mass in dynes per unit velocity, or dynes per kine.

The simplification in the vibrational system represented in the transition from Fig. 1 to Fig. 2 seems justified from experimental results.

Magnetomotive Force Damped and Free. When the diaphragm is damped, or prevented from vibrating, a simple alternating current of I r. m. s. absamperes will develop a corresponding simple alternating m.m.f. of $\mathfrak{F}_i$ r. m. s. gilberts, in phase with I. This may be represented as in Fig. 3, by the plane vector f_i in the horizontal or reference-phase position. In the receiver analysed, the testing current I was 0.000204 absamperes r. m. s., and taking the number of turns on the two coils together as 1300, the m.m.f. thereby produced would be

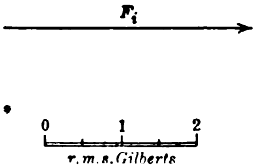

FIG. 3—M. M. F. DIAGRAM AT CONSTANT CURRENT—DIAPHRAGM DAMPED

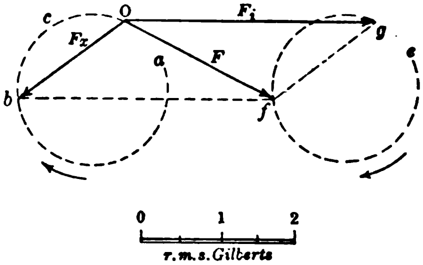

FIG. 4—M. M. F. DIAGRAM AT CONSTANT CURRENT AND 1028 CYCLES PER SEC. DIAPHRAGM FREE

$$4\,\pi \times 1300 \times 0.000204 = 3.334 \text{ gilberts r. m. s.}$$

This is represented, to a scale of 1.0 gilbert per linear cm. in Fig. 1, as a vector 3.33 cm. in length.

When the diaphragm is free, or allowed to vibrate, the same exciting current will produce the same m. m. f. as before; but a new periodic m. m. f. will be developed in the magnetic circuit, owing to the periodic change in diaphragm displacement, and length of airgap; so that the reluctance in the circuit of the permanent magnet will be periodically varied accordingly.

Let $\mathfrak{F}_0$ = the m. m. f. of the permanent magnet (gilberts)
$\mathfrak{R}_0$ = the reluctance in the permanent magnetic circuit (oersteds)
Φ_0 = the magnetic flux across the airgaps in the circuit (maxwells)

Then in the magnetic circuit of the permanent magnet, there will be a permanent magnetic flux which, neglecting magnetic leakage through the surrounding air, will be

$$\Phi_0 = \frac{\mathcal{F}_0}{\mathcal{R}_0} \qquad \text{maxwells} \quad (\mathbf{1})$$

If the diaphragm is now caused to vibrate, by reason of independent variations of this magnetic flux due to alternating current in the coils, the reluctance in each airgap of area S sq. cm. will be varied by $-\dfrac{dx}{S}$ oersteds, if dx is the displacement of the diaphragm from its normal position, towards the pole; so that the total change in reluctance will be $-\dfrac{2\,dx}{S}$ oersteds.

But differentiating (**1**)

$$\frac{\partial\,\Phi_0}{\partial\,\mathcal{R}_0} = -\frac{\mathcal{F}_0}{\mathcal{R}_0^2} = -\frac{\Phi_0}{\mathcal{R}_0}\,. \qquad \frac{\text{maxwells}}{\text{oersteds}} \quad (\mathbf{2})$$

or $$\partial\,\Phi_0 = -\Phi_0\,\frac{\partial\,\mathcal{R}_0}{\mathcal{R}_0} \qquad \text{maxwells} \quad (\mathbf{3})$$

but $\partial\,\mathcal{R} = -2\,\partial\,x/S$; so that

$$\partial\,\Phi_0 = \Phi_0 \cdot \frac{2\,\partial\,x}{S\,\mathcal{R}_0} = \mathcal{B}_0 \cdot \frac{2\,\partial\,x}{\mathcal{R}_0} \qquad \text{maxwells} \quad (\mathbf{4})$$

This differential change in the flux through the magnetic circuit is such as would correspond to the action of a certain differential impressed m. m. f. $\partial\,\mathcal{F}_0$, such that

$$\frac{\partial\,\mathcal{F}_0}{\mathcal{R}_0} = \partial\,\Phi_0 \qquad \text{maxwells} \quad (\mathbf{5})$$

Consequently, substituting in (**4**)

$$\partial\,\mathcal{F}_0 = \mathcal{B}_0 \cdot 2\,\partial\,x \qquad \text{gilberts} \quad (\mathbf{6})$$

If, then, we know $\mathcal{B}_0$, the normal mean flux density across the airgaps, an alternating displacement of $\partial\,x$ cms. r. m. s. towards the poles at reference phase, will generate an equivalent vector m. m. f. according to (**6**) in phase with $\partial\,x$. This is shown in Fig. 4 by the plane vector $\mathcal{F}_x$. The phase of $\mathcal{F}_x$ with respect to $\mathcal{F}_i$ cannot be assigned until we know the phase of the diaphragm displacement ∂x, but means for determining this phase difference will be indicated later on. The locus of $\mathcal{F}_x$ is indicated in Fig. 4. It is a "displacement-admittance" locus.

At a very low frequency, $\mathfrak{F}_x$ would occupy the plane-vector position $O\,a$. At a very high frequency, it would disappear towards $O\,c$. It would, therefore describe the locus $a\,b\,c$ in the direction of the arrow.

The resultant m. m. f. in the circuit is the planevector sum of $\mathfrak{F}_i$ and $\mathfrak{F}_x$, and is indicated in Fig. 4 by $\mathfrak{F}$. At low frequencies, the size of $\mathfrak{F}$ exceeds the size of $\mathfrak{F}_i$; but towards higher frequencies, the size of $\mathfrak{F}$ falls below that of $\mathfrak{F}_i$. The effect, therefore, of the vibration of the diaphragm is to change the constant impressed a-c. m. m. f. $\mathfrak{F}_i$ to a correspondingly varied m. m. f. following the vector locus $e\,f\,g$, as the frequency is changed.

In Figs. 3 and 4, the vectors represent, to scale, the approximate values of $\mathfrak{F}_i$, $\mathfrak{F}_x$ and $\mathfrak{F}$, as derived from experimental tests of the selected instrument.

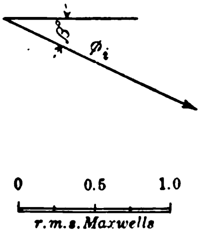

Fig. 5—Flux Diagram at 1028 Cycles per Sec. — Diaphragm Damped

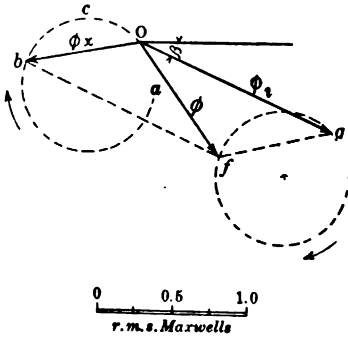

Fig. 6—Flux Diagram at 1028 Cycles per Sec. — Diaphragm Free

Magnetic Flux, Damped and Free. In Figs. 5 and 6, the planevector alternating magnetic fluxes are represented with the diaphragm damped and free. When damped, as in Fig. 5, the alternating m. m. f. of $\mathfrak{F}_i$ r. m. s. gilberts at reference phase, produces an alternating magnetic flux of ϕ_i r. m. s. maxwells, lagging in phase $\beta°$ behind the m. m. f. The reason for the lag is partly on account of magnetic hysteresis, and partly on account of magnetic skin effect. This angle $\beta°$ (25.3 deg. in Fig. 5) can be determined from the observed motional-impedance diagram, on the assumption already made that β is half the depression angle of the motional-circle diameter. In certain cases, β is found to exceed 54 deg. although it is, more commonly in the neighborhood of 30 deg.

In Fig. 6, on the assumption already made that the lag $\beta°$ is the same to both $\mathcal{F}_i$ and $\mathcal{F}_x$; *i. e.*, that ϕ_x lags $\beta°$ behind $\mathcal{F}_x$, we obtain the fluxes ϕ_i and ϕ_x with their resultant ϕ, as well as the approximate loci over which they travel under change of impressed frequency, β being taken as substantially constant over that range.

Actual observation shows that the angle of lag β_1 between $\mathcal{F}_i$ and ϕ_i is not, in general, identical with the angle of lag β_2 between $\mathcal{F}_x$ and ϕ_x, but their sum is 2 β, and the discrepancy is here neglected.*

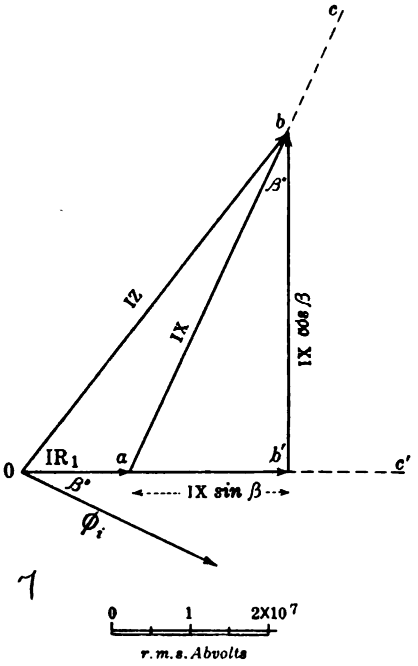

FIG. 7—E. M. F. DIAGRAM AT 1028 CYCLES PER SEC.—DIAPHRAGM DAMPED

Electromotive Forces, Damped and Free. Fig. 7 shows the alternating e. m. f. planevector diagram when the diaphragm is damped. With constant exciting current strength I r. m. s. absamperes, and constant assumed resistance R_1 absohms in the winding, the vector $I R_1$ r. m. s. volts, expended in overcoming the winding resistance, will theoretically remain constant at all frequencies. The voltage expended in overcoming the reactance of the winding will be $I X$ r. m. s. volts, at a leading slope of $90 - \beta°$; because this voltage must be in leading quadrature to the flux ϕ_i. The resultant voltage $I Z$ is that which must be applied to the terminals of the receiver, in order to maintain in its winding the required constant current strength I. The locus of the impressed voltage $I Z$ on the preceding assumptions, will therefore be the straight line *a b c*.

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*Bibliography 18.

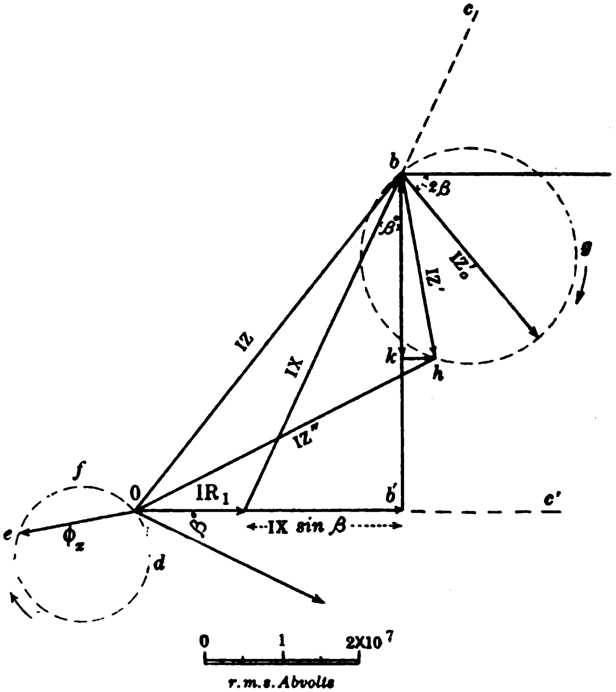

FIG. 8—E. M. F. DIAGRAM AT 1028 CYCLES PER SEC.—DIAPHRAGM FREE

The inductive voltage or voltage expended in overcoming the counter e. m. f. of induction is *a b* on the diagram and is expressed by $j I \mathcal{L} \omega$ abvolts ∠, where $\mathcal{L}$ is a vector inductance of slope ∖ $\beta°$ as defined by the relation

$$\mathcal{L} = 4 \pi N^2 \mathcal{P} \qquad \text{abhenries } \angle \quad \textbf{(6a)}$$

where $\mathcal{P}$ is a vector permeance expressed in maxwells per gilbert ∠, or 1/oersteds ∠. The corresponding apparent resistance voltage is $O b'$ traversing the locus $a b' c'$. The apparent reactance voltage is $b'\,b$. This apparent reactance voltage, as obtained from impedance measurements with damped diaphragm, is

$$I\,|X|\cos\beta = I\,|\mathfrak{L}|\,\omega\cos\beta \qquad \text{abvolts} \quad (7)$$

Here the symbol $|\mathfrak{L}|$ denotes the size of $\mathfrak{L}$ as a scalar.

The apparent inductance $\mathfrak{L}$ of the winding should also remain constant. Actually, observations show that the apparent inductance diminishes as the frequency is increased, owing to the influence of changes in magnetic skin effect, which are assumed to be negligible in the stage of telephone theory here aimed at.

Fig. 8 represents the corresponding planevector e. m. f. diagram, with diaphragm free. In this diagram, the additional periodic flux ϕ_x, taken from Fig. 6, is included, and runs over the locus $d\,e\,f$. The vector impressed voltage $I\,Z''$, travels over the straight line locus $a\,b\,c$, as in Fig. 7; but at its end, there is added an e. m. f. locus due to the time variation of ϕ_x, which is a circle $b\,g\,h$. This circle moves parallel to itself, along the lengthening line $a\,b\,c$. The vector $b\,h$ is in leading quadrature to ϕ_x, in the position $O\,e$, and represents the motional impedance voltage $I\,Z'$ at this frequency, or the voltage expended in overcoming the displacement e. m. f. of the diaphragm considered as a motor element. The e. m. f. $I\,Z''$ which must be impressed at receiver terminals, in order to maintain constant current I, is represented by $O\,h$ abvolts. The component $O\,h'$, is the cophase component of e. m. f. and $b'\,k$ the quadrature or reactive component.

Impedances, Damped, Free and Motional. Figure 7, the damped voltage diagram, might also serve as an impedance diagram, if its various vectors are divided by the constant current I, and if, therefore, these vectors are read off to an appropriate scale of absohms. In Fig. 9, the transition is made, however, to a convenient resistance scale. The apparent resistance is $O\,b = R_1 + |X|\sin\beta$ absohms, the apparent reactance $b'\,b = |X|\cos\beta$ absohms, and the impedance with damped diaphragm

$$Z = O\,b = R_1 + |X|\sin\beta + j\,|X|\cos\beta = R_1 + X \quad \text{absohms} \angle \qquad (8)$$

As the impressed frequency increases, the impedance travels over the locus $a\,b\,c$. In Fig. 1 of the paper referred to, (Bibliography 17), the vector damped impedance locus makes an angle of β = 25.°3, very nearly, with the reactance axis, between f = 700 ~ and f = 1500 ~.

Fig. 10 shows the corresponding impedance of the instrument with the diaphragm free. The vector $O\,b$ pursues the same path $a\,b\,c$ as in Fig. 9; but at its end, there is added a traveling circular locus $g\,h\,k$. The impedance of the instrument is Z'', and we have the vector relation.

$$Z' = Z'' - Z \qquad \text{absohms} \angle \quad (9)$$

The vector path of Z', plotted separately, is the stationary circle

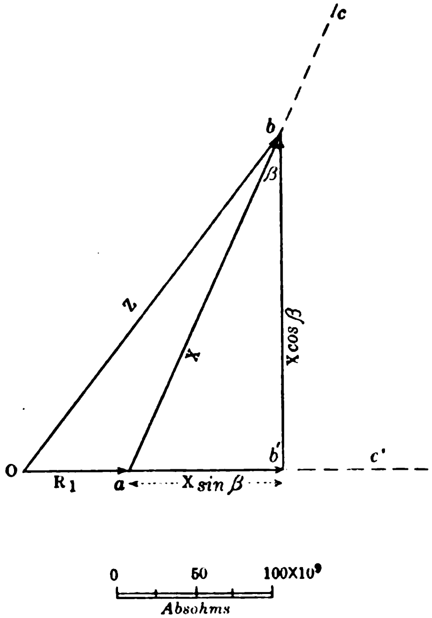

FIG. 9—IMPEDANCE DIAGRAM—DIAPHRAGM DAMPED

$b\,g\,h$, and this circle is obtained from experimental observations at constant current. It passes through the origin of coordinates like the circle of Fig. 27. It has a diametric depression angle, or lag angle, of 2 β, because the diameter being produced at resonant frequency, the displacement velocity $\dot{x}$ of the diaphragm is then in phase with the flux ϕ_i, which is $\beta°$ behind the current, and the displacement x is then in lagging quadrature with the velocity or $(90° + \beta)$ behind the current. But ϕ_x is $\beta°$ behind the displacement x (Fig. 6) and is therefore $90° + \beta°$ behind the velocity $\dot{x}$ or $90° + 2\,\beta°$ behind I. The e. m. f.

$I Z'$, Fig. 8, due to the variation of ϕ_x, being in leading quadrature therewith, is then $2\,\beta°$ behind I, and Z', at resonance, is thus $2\,\beta°$ behind the reference phase, or resistance axis.

Every telephone receiver has its own particular motional impedance circle, which is very sensitive to changes in temperature or in mechanical adjustment. Motional impedance circles differ:

1. In their size, or diametral length.
2. In their depression angle $2\,\beta$.
3. In the distribution of frequencies around the circle.

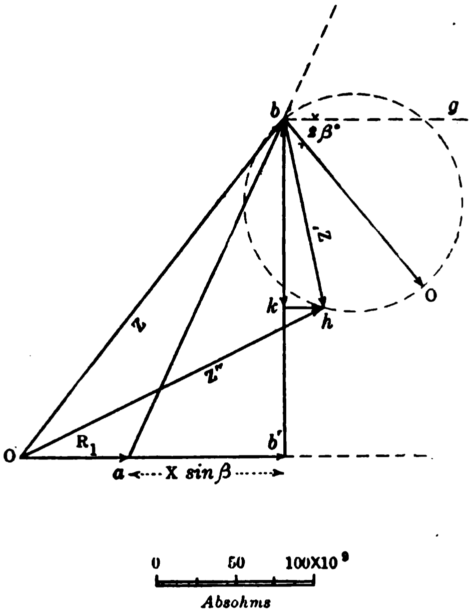

FIG. 10—IMPEDANCE DIAGRAM—DIAPHRAGM FREE

Sharply resonant instruments will pass from the lower quadrantal frequency f_1, to the upper f_2, over half the circle, with a change of only a very few cycles per second. On the other hand, bluntly resonant instruments may require a change in frequency of several hundred cycles per second, to pass over the same range of locus.

Having found by observation the depression angle $2\,\beta$ of the motional impedance circle, the angle β is known, and the construction of Figs. 9 and 10 may be carried out, with the angle at $b\,b'$ made equal to β. Knowing the apparent resistance $O\,b'$, and the apparent reactance $b'\,b$, at various impressed frequencies, as well as $\beta°$, we can readily compute R_1 and $\mathcal{L}$ from (7) and (8). R_1 should theoretically be substantially constant under the assumption that $\mathcal{L}$ is constant. For the instrument here considered, the following Table gives the values of R_1 as computed from the observed resistances with damped diaphragm, and the angle β assumed constant at resonant value.

Frequency cycles per sec.	Angular Velocity rad. per sec. ω	Measured Resistance absohms at 20 deg. cent. R	Active component of inductive resistance $R_h = \omega \mathcal{L}_0 \sin \beta$	Reactive component of inductive resistance $X = \omega \mathcal{L}_0 \cos \beta$	$R_1 = R - R_h$ absohms
0	0	86.7×10^9	0×10^9	0×10^9	86.7×10^9
429	2694	124 "	41.9 "	89 "	82.1 "
702	4420	145 "	68.8 "	146 "	76.2 "
923.4	5801	162 "	90.5 "	191.5 "	71.5 "
*1015	6378	168.4 "	99.5 "	210.5 "	68.6 "
1306	8202	189. "	128 "	270.7 "	61. "
1507	9460	204 "	147.6 "	314.1 "	56.4 "

*Resonant frequency.

The steady apparent fall in the values of R_1 as the frequency was increased, may be attributed to the influence of changes in magnetic skin effect here neglected.

Electric Power, Damped and Free. With the diaphragm damped, the vector diagram of either Fig. 7, or Fig. 9, might serve as a power diagram, if read off to a corresponding scale of abwatts, or ergs per second. The power diagram is repeated, however, in Fig. 11 to a convenient power scale. $O\,a$ is active power, $I^2 R_1$ abwatts, expended in heating the winding. $I^2 X$ is the vector power $a\,b$, expended in the magnetic circuit. It follows the locus $a\,b\,c$, as the frequency is varied. The active component $a\,b' = I^2 \mid X \mid \sin \beta$, is dissipated thermally in the magnetic circuit, in hysteresis and eddy currents. The reactive component $b'\,b = I^2 \mid X \mid \cos \beta$ is utilized in alternately storing and releasing energy in the magnetic circuit.

When the diaphragm is freed, the power conditions are indicated vectorially in Fig. 12. $O\,a$, as before, is the thermal power $I^2 R_1$, dissipated in the winding. The power delivered to the magnetic circuit is $a\,h$, which is in leading quadrature to the resultant flux ϕ, see Fig. 6. The active component $a\,h'$ includes the power expended in hysteresis and eddy currents, and also the active mechanical power delivered from the magnetic circuit to the diaphragm. The reactive component *h′ h* includes power utilized in storing and releasing magnetic energy in the magnetic circuit, and also power utilized in storing and releasing reactive mechanical energy in the diaphragm.

Mechanical Velocity, Damped and Free. When the diaphragm is damped, the vibrational velocity of displacement must be zero. When, however, the diaphragm is free, the velocity of displacement $\dot{x}$ will have a definite magnitude and phase. If we assume the vibromotive force $f_i = Og$ r. m. s. dynes, Fig. 13, to remain constant at all frequencies, the locus of the vector velocity $\dot{x}$ will be the circle *O a b c*. This mechanical relation has its complete electric analogy in the simple alternating-current circuit of Fig. 14, where a simple harmonic e. m. f. *E*, of constant r. m. s. magnitude, and at standard phase; supplies the simple circuit *C R L* at successively varied frequencies. All of the resistance of the circuit, assumed constant, is located in the resistor *R*, all of the inductance in the inductor *L*, and all the capacitance in the condenser *C*. At a very low frequency, the impedance of the circuit will

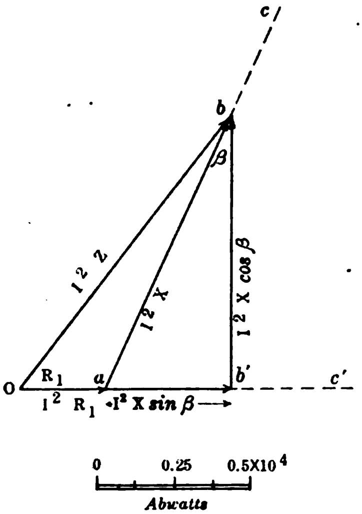

FIG. 11—ELECTRIC POWER DIAGRAM—DIAPHRAGM DAMPED

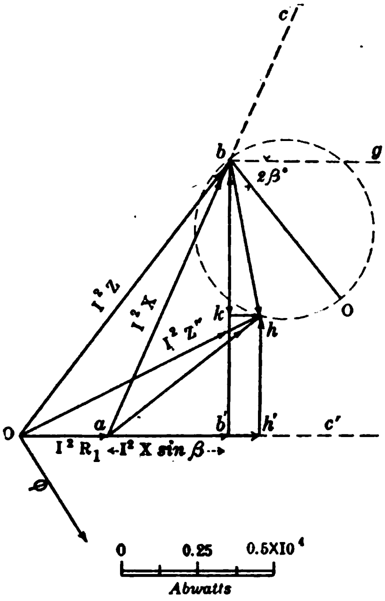

FIG. 12—ELECTRIC POWER DIAGRAM—DIAPHRAGM FREE

be large and entirely due to the condenser C. The alternating current will be very feeble and will lead the impressed e. m. f. by 90°. As the frequency is raised, the impedance diminishes, both in size and in slope. The current strength will therefore increase in magnitude, and come more nearly into phase with E. As is shown in Fig. 15, when the resonant frequency of the circuit is attained, the current will be a maximum at I_0, and will be in phase with E. Finally, as the frequency becomes very high, the current will disappear, and lag 90° behind E. The locus of the vector current will be the circle $O\ a\ b\ c$, Fig.15.

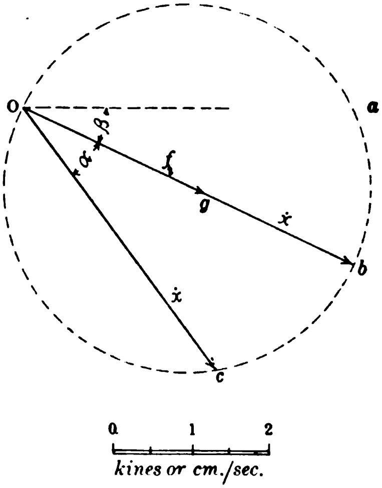

FIG. 13 — VELOCITY DIAGRAM — DIAPHRAGM FREE — CONSTANT V. M. F. AND VARIED FREQUENCY

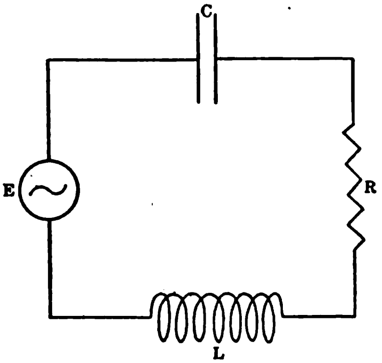

FIG. 14—SIMPLE ALTERNATING-CURRENT CIRCUIT UNDER CONSTANT E. M. F. AND VARIED FREQUENCY

If, in the mechanical system of the diaphragm, the equivalent mass replaces the inductance L, the stiffness s of the diaphragm, replaces $1/C$, and the mechanical resistance to motion r replaces R; also the vibromotive force f_i replaces E; then the vibrational velocity $\dot{x}$ will correspond both in magnitude and phase to the alternating current strength I. The phase lag α of the velocity is then equal to the slope of the mechanical impedance

$$r + j\,(m\,\omega - s/\omega) \qquad \text{mechanical ohms} \angle$$

Mechanical Displacement. The mechanical displacement of the diaphragm at elongation corresponds, in the electrical system of Fig. 15, to the displacement of electricity at cyclic elongation. It is represented in Fig. 16 by the vector $O\,c$. This vector is in lagging quadrature to the vector $O\,c$ of Fig. 13, at one and the same impressed frequency. The locus of x is the displacement curve $a\,b\,c\,O$.

Force Diagram Damped and Free. If the diaphragm is damped, any single vibromotive force (v. m. f.) f_i, Fig. 17a, will develop a counter v. m. f. f_c, which will make the resultant force zero; so that no displacement results. If, however, the diaphragm is free, there will be four forces called into action, in similarity to those in the corresponding electrical case of Fig. 15; namely, the impressed single v. m. f. f_i, Fig. 17, in phase with the flux ϕ_i; the frictional resisting force $-r\dot{x}$ dynes, the inertia force $-j\omega m\dot{x}$ dynes, and the elastic force $j\dfrac{s\dot{x}}{\omega}$ dynes. These are represented in Fig. 17 by the vectors $O\,a$, $O\,b$, $O\,c$ and $O\,d$. Since $O\,c$ and $O\,d$ must be mutually opposite, their difference $O\,e$, combined with $O\,b$, must balance the impressed force $O\,a$. This relation determines the position and magnitude of the velocity $\dot{x}$. We have already seen that as the frequency is changed from a small to a large value, the locus of $\dot{x}$ is a circle about O. At mechanical resonance, $\dot{x}$ will have a maximum size and zero slope, or will coincide with f_i in direction. The

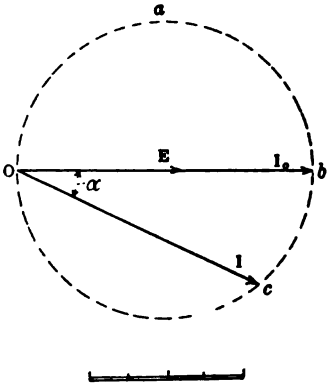

FIG. 15—CURRENT DIAGRAM IN SIMPLE A-C. CIRCUIT, UNDER CONSTANT E. M. F. AND VARIED FREQUENCY

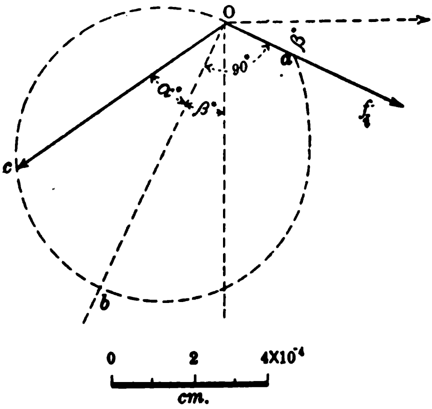

FIG. 16—DISPLACEMENT DIAGRAM—DIAPHRAGM FREE

displacement x, not indicated in Fig. 17, will always have the direction $o\,c$, 90° lagging behind $\dot{x}$.

The vector force equation is in the rotatable vector diagram of Fig. 17.

$$m\ddot{x} + r\dot{x} + s\,x = f_i \qquad \text{r. m. s. dynes} \angle \quad \mathbf{(10)}$$

or since x is a simple harmonic displacement of the type $x_m\,\epsilon^{j\omega t}$,

$$j\,\omega\,m\dot{x} + r\dot{x} + \frac{s\,\dot{x}}{j\omega} - f_i = 0 \qquad \text{r. m. s. dynes} \angle \quad \mathbf{(11)}$$

Fig. 17A—Force Diagram —Diaphragm Damped

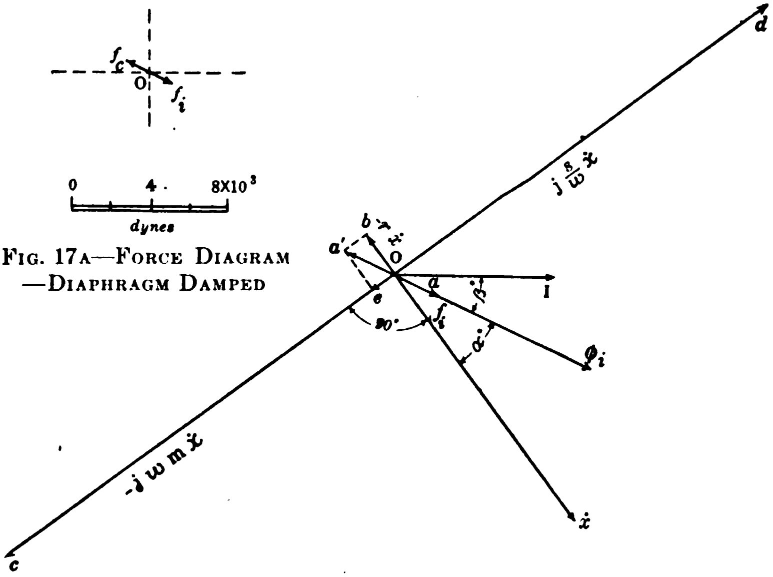

Fig. 17—Force Diagram for the Ideal Case of a Diaphragm Free to Vibrate Under a Single Impressed V. M. F. f_i R. M. S. Dynes

$$\text{or} -j\,\omega\,m\dot{x} - r\dot{x} + j\dot{x}\,s/\omega + f_i = 0 \qquad \text{r. m. s. dynes} \angle \quad \mathbf{(12)}$$

whence

$$\dot{x} = \frac{f_i}{r + j\,(m\,\omega - s/\omega)} \qquad \text{r. m. s.}\ \frac{\text{cm.}}{\text{sec.}} \angle \quad \mathbf{(13)}$$

which corresponds completely to Ohm's law in the vector simple alternating-current case.

The specific magnetic force acting at any time on the diaphragm, towards the magnetic poles, is $\frac{\mathcal{B}^2}{8\,\pi}$ dynes per sq.

cm., where $\mathcal{B}$ is the total magnetic flux density. This flux density comprises the permanent magnetic flux density $\mathcal{B}_0$ gausses, and the alternating flux density $\mathcal{B}$ instantaneous gausses. The total magnetic force is thus

$$\frac{2S}{8\pi}(\mathcal{B}_0 + \mathcal{B})^2 = \frac{S}{4\pi}(\mathcal{B}_0 + \mathcal{B})^2$$

$$= \frac{S}{4\pi}(\mathcal{B}_0^2 + 2\,\mathcal{B}_0\,\mathcal{B} + \mathcal{B}^2) \qquad \text{instantaneous dynes} \quad (14)$$

Since $\mathcal{B}^2$ is very small by comparison with $\mathcal{B}_0^2$, it may be neglected in the summation, and the instantaneous force in the diaphragm is

$$\frac{S}{4\pi}(\mathcal{B}_0)^2 + \frac{S}{4\pi}\cdot 2\,\mathcal{B}_0\,\mathcal{B} \qquad \text{instantaneous dynes} \quad (15)$$

The first term is the permanent force which flexes the diaphragm from its plane position, and which plays no material part in the alternating regime here considered. The second term includes the periodic quantity $\mathcal{B}$, which may be represented vectorially by a vector of size $\mathcal{B}_i$ r. m. s. gausses, lagging $\beta°$ behind the exciting m. m. f. $\mathcal{F}_i$. But $S\,\mathcal{B}_i = \phi_i$ the r. m. s. vector flux in phase with $\mathcal{B}_i$, so that in the damped condition,

$$\phi_i = \mathcal{F}_i\,\mathcal{P} = 4\,\pi\,N\,I\,\mathcal{P} \qquad \text{r. m. s. maxwells} \angle \quad (16)$$

where I is the r. m. s. exciting current in absamperes, N the total number of turns including both coils, and $\mathcal{P}$ a vector permeance which possesses a lag angle $\beta°$. Consequently from (15)

$$f_i = 2\,\mathcal{B}_0\,N\,\mathcal{P}\,I = A\,I \qquad \text{r. m. s. dynes} \angle \quad (17)$$

or in a bipolar instrument $A = 2\,\mathcal{B}_0\,N\,\mathcal{P}$ r. m. s. dynes per absampere $\angle$ (18)

A is a vector force factor with a lag angle of $\beta°$.

We have thus far supposed that only one periodic force f_i acts on the diaphragm. There is, however, a second periodic force introduced by the flux ϕ_x, due to the displacement m. m. f., the magnitude of which is proportional, by (6), to the maximum cyclic value of the displacement, and which has the same phase as that displacement.

We have already shown in (6) that the displacement m. m. f. is

$$F_x = 2\,\mathcal{B}_0\,x \qquad \text{r. m. s. gilberts} \angle \quad (19)$$

This may be considered as similar to the m. m. f. of current

$$\mathfrak{F}_i = 4\,\pi\,N\,I \qquad \text{r. m. s. gilberts} \angle \quad (\mathbf{20})$$

so that a certain number of turns N' multiplied by the r. m. s. vector displacement, would produce the same m. m. f. as the actual number of turns N multiplied by the corresponding r. m. s. vector current. Consequently, in the case of a bipolar receiver

$$N' = \frac{\mathcal{B}_0}{2\,\pi} \qquad \text{equivalent turns} \times \frac{\text{absampere}}{\text{cm.}} \quad (\mathbf{21})$$

If we consider the ratio

$$\frac{N'}{N} = p \qquad \frac{\text{absampere}}{\text{cm.}} \quad (\mathbf{22})$$

which, in the instrument considered, was 0.168,

$$\mathfrak{F}_x = 4\,\pi\,N'\,x \qquad \text{r. m. s. gilberts} \angle \quad (\mathbf{23})$$

and from (**17**)

$$f_x = p\,A\,x = 2\,p\,\mathcal{B}_0\,N\,\mathcal{P}\,x \qquad \text{r. m. s. dynes} \angle \quad (\mathbf{24})$$

It may be noted, in passing, that just as in the case of a vector electromagnetic inductance

$$\mathcal{L} = A/p = 4\,\pi\,N^2\,\mathcal{P} \qquad \text{abhenries} \angle \text{ or ergs per absamp}^2 \angle \quad (\mathbf{25})$$

so

$$p\,A = 4\,\pi\,N'^2\,\mathcal{P} \qquad \frac{\text{r. m. s. dynes}}{\text{cm.}} \angle \quad (\mathbf{26})$$

and is a quantity bearing resemblance to an inductance. From (**25**) and (**26**)

$$A = 4\,\pi\,N\,N'\,\mathcal{P} \qquad \frac{\text{r. m. s. dynes}}{\text{absamp}} \angle \quad (\mathbf{27})$$

so that, in this sense, the force factor A bears resemblance to a mutual inductance.

The additional force f_x, due to ϕ_x, may be introduced into the problem either (**1**) by vector summation with f_i, to form a vector resultant force f, corresponding to ϕ in Fig. 6; or (**2**), by retaining f_i as the sole active force on the diaphragm, and introducing the action of f_x in the form of a mechanical impedance. For practical purposes, the latter method is to be preferred, just as in the simple alternating-current circuit, the effect of a counter e. m. f. of self induction is usually treated as an impedance, instead of being combined vectorially with the impressed e. m. f. in the numerator of Ohm's law.

The force f_x lags behind the displacement x by the angle $\beta°$, according to the relation

$$f_x = p\,A\,x = \frac{p\,A\,\dot{x}}{j\,\omega} = -j\,p\,A\,\frac{\dot{x}}{\omega} \quad \text{r. m. s. dynes} \angle \qquad \textbf{(28)}$$

or 90° + $\beta°$ behind the phase of the velocity $\dot{x}$.

In Fig. 18, the force f_x is represented in a particular case with the diaphragm free. Here the m. m. f. $\mathfrak{F}_i$ is taken as of reference phase, with f_i lagging $\beta°$ behind it. This force f_i must now equilibrate four forces; namely, the elastic force $O\,d$, the inertia force $O\,c$, the frictional force $O\,b$, and the new magnetic force $O\,e$, whose components, along the $O\,b$ and $O\,c$ directions, are indicated as $O\,e'$ and $O\,e''$ respectively. With $\mathfrak{F}_i$ at reference phase, the locus of the new force $O\,e$ is a displacement-admittance locus like $a\,b\,c$ in Fig. 4; but considered solely with reference to the velocity $\dot{x}$, $O\,e$ always lags with respect thereto by 90° + $\beta°$. The components $O\,e'$ and $O\,e''$ may be defined as $-\,r'\,\dot{x}$ and $\dfrac{-j\,s'\,\dot{x}}{\omega}$ respectively; where r' is a virtual frictional resistance, and s' a virtual stiffness coefficient.

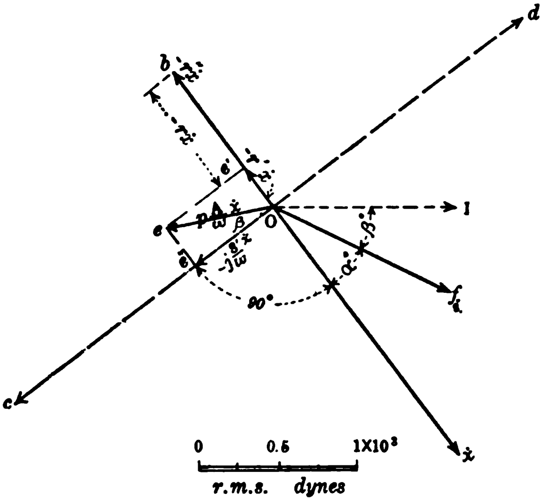

FIG. 18—FORCE DIAGRAM INCLUDING MAGNETIC FORCE DUE TO DISPLACEMENT—DIAPHRAGM FREE ENLARGED SCALE

The diaphragm therefore behaves as though its frictional resistance were increased by

$$r' = \frac{p\,|A|}{\omega}\sin\beta \qquad \frac{\text{dynes}}{\text{kine}} \qquad (29)$$

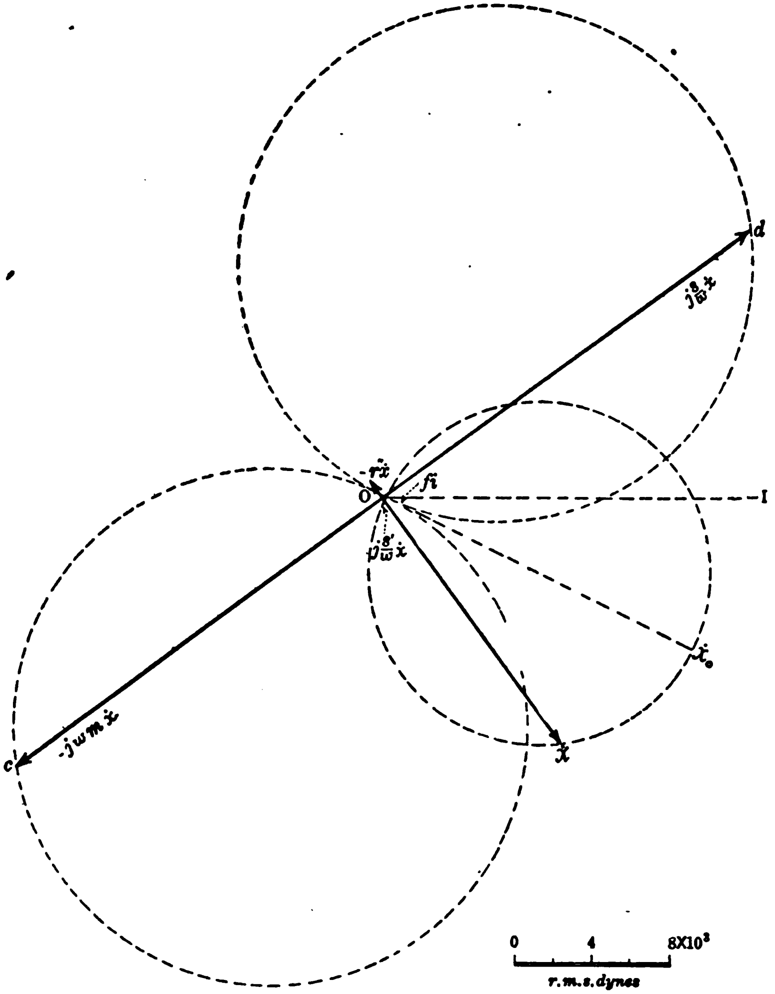

FIG. 19—FORCE DIAGRAM—COMPLETE—INCLUDING MAGNETIC FORCE DUE TO DISPLACEMENT

while the stiffness of the diaphragm is apparently diminished by

$$s' = p\,|A|\cos\beta \qquad \frac{\text{dynes}}{\text{cm.}} \qquad (30)$$

The values of r' and s' can be assigned, when A, β, and p are known. In the instrument considered, at resonance, $r' = 68.8$ dynes per kine and $r = 199$ dynes per kine, r' diminishing, according to our theory, as ω is increased. Also s' is 9.3×10^5 dynes per cm. as against $s = 376 \times 10^5$. According to our theory, s' is thus only about 3 per cent of s, at all frequencies.

In Fig. 19, the loci of the inertia and stiffness forces, $O\,c$ and $O\,d$, are represented to scale, without including therein the components $O\,e'$ and $O\,e''$, Fig. 18, of the added magnetic force f_x. The directions of motion in the loci, with increase of frequency are all clockwise. The locus of $O\,d$ is a displacement-admittance locus, obtained from the circular locus of $\dot{x}$ by time integration; whereas the locus of $O\,c$ is obtained from that of $\dot{x}$ by time differentiation.

The total mechanical impedance of the diaphragm from (**13**) and (**28**) is

$$z' = r + j\,(m\,\omega - s/\omega) + j\,\frac{p\,A}{\omega} \qquad \frac{\text{dynes}}{\text{kine}} \quad \angle \quad (\mathbf{31})$$

The reciprocal of this quantity, or mechanical admittance y' is

$$\begin{aligned} y' &= 1/z' \\ &= \frac{1}{\sqrt{r''^2 + (m\,\omega - s''/\omega)^2}} \angle \tan^{-1}\left(\frac{m\,\omega - s''/\omega}{r''}\right) \\ &= \frac{1}{\sqrt{(r + r')^2 + \left(m\,\omega - \dfrac{s - s'}{\omega}\right)^2}} \\ &\quad \cdot \angle \tan^{-1}\left(\frac{m\,\omega - \dfrac{s - s'}{\omega}}{r + r'}\right) \qquad \frac{\text{kines}}{\text{dyne}} \quad \angle \quad (\mathbf{32}) \end{aligned}$$

The values of r' and s' are to be taken from (**29**) and (**30**). This vector admittance y', multiplied by the constant impressed mechanical force f_i, due to the constant alternating current, gives the mechanical velocity $\dot{x}$, or

$$\dot{x} = f_i\,y' = A\,y'\,I \qquad \text{r. m. s.}\ \frac{\text{cm.}}{\text{sec.}} \quad \angle \quad (\mathbf{33})$$

and the r. m. s. displacement x by

$$x = -j\,f_i\,y'/\omega = -j\,A\,y'\,I/\omega \quad \text{r. m. s. cyclic cm.} \quad \angle \quad (\mathbf{34})$$

The actual maximum cyclic displacement of the diaphragm is then

$$x_m = |x| \sqrt{2} \qquad \text{max. cyclic cm.} \quad (35)$$

Motional Electromotive Force Diagram. Referring to Fig. 16, the vector displacement Oc is determined by equation (**34**), and the vector velocity Oc in Fig. 13, by equation (**33**), in terms of the motional constants r, r', m, s and s', as well as A. The displacement flux ϕ_x, Fig. 8, is then obtained through (**23**) or

$$\phi_x = \frac{p\,A\,x}{N'} = 4\,\pi\,N'\,x\,\mathcal{P} \qquad \text{maxwells} \angle \quad (36)$$

The e. m. f. produced by ϕ_x in the coils is the motional e. m. f. and is

$$I\,Z' = j\,\omega\,\frac{p\,A\,x}{N'}\,N = j\,\omega\,A\,x$$
$$= A\,\dot{x} = A^2\,y'\,I \qquad \text{abvolts} \angle \quad (37)$$

It may be noted that since $\dot{x}$ is a velocity in kines, the vector dimensions of A are not only expressed by dynes per absampere, as in (**18**) or (**27**), but also by abvolts per kine, as in (**37**).

The vector motional e. m. f. $I\,Z'$, Fig. 8, is in leading quadrature to $O\,e$, the displacement flux. Since in (**37**), this vector is directly proportional to the velocity $\dot{x}$, which has been shown to travel over a circular locus, when, as in (**13**), a single periodic force is impressed upon the diaphragm, the motional e. m. f. $I\,Z'$ must also have a circular locus, as shown in Fig. 8, when the second force f_x is negligible; *i. e.*, when p in (**28**) may be taken as zero. When p is appreciable, the subsidiary constants r' and s' are introduced into the motional equations (**32**) and (**33**). It will be seen that s' merely reduces the stiffness coefficient s of the diaphragm by the same amount at all frequencies; but r' varies with the frequency inversely, as shown by (**29**). The theoretical effect of r' is therefore to distort the locus of the motional e. m. f. $I\,Z'$, from a circle, to an extent depending on the magnitude of $p\,A$, and also upon the range of frequency necessary for the execution of the circle; *i. e.*, upon the bluntness of mechanical resonance. Since in a bipolar instrument

$$p\,A = \frac{\mathcal{B}_0^2\,\mathcal{P}}{\pi} \qquad \frac{\text{dynes}}{\text{cm.}} \angle \quad (38)$$

an instrument which has a relatively powerful permanent magnetic flux density $\mathcal{B}_0$ in the airgaps, and also large magnetic-circuit permeance, is one in which the force f_x tends to be greatest, by (**28**). This, with a large value of β and a wide range of ω for executing the circle, would give rise to the largest distortion. In practice, the distortion is usually not sufficiently serious to be very noticeable, probably because the range in ω within which half of the circle is executed, is ordinarily only a few hundreds of radians per second. In the case considered, $\omega_2 - \omega_1 = 305$.

It is evident, moreover, from (**37**) that the lagging displacement of vector $I\,Z'$ with respect to I, is that of $A^2\,y'$, and since, at resonance, the slope of y' vanishes (**32**), it will then be the displacement of A^2, or $-2\ \beta°$, and $A^2 = Z_0'\,r''$.

At resonance, the size of $I\,Z'$, the motional e. m. f. will, by (**37**) be

$$I\,Z_0' = \frac{A^2\,I}{r''} \qquad \text{abvolts} \angle \quad (\mathbf{39})$$

Motional Impedance. Referring to Fig. 10, the motional impedance executes a circular locus similar to that in Fig. 8, neglecting the disturbing influence of r' at different frequencies. At resonance, its size is

$$Z'_0 = A^2/r'' \qquad \text{absohms} \angle \quad (\mathbf{40})$$

and its slope is that of A^2 or $-2\ \beta°$.

From an experimental standpoint, the motional-impedance circle is of primary importance, as, from it, the motional constants may be derived, if the maximum cyclic displacement at resonance

$$x_m = |\,x_0\,|\ \sqrt{2} \qquad \text{cm.} \quad (\mathbf{41})$$

can be measured.

Technique for Deriving the Constants A, m, r'', r', r, s'', s, p and β. (1) The motional-impedance circle is obtained from observations of the apparent resistance and reactance of the instrument, both free and damped, with constant testing current, under adjustably varied frequency. This gives the resonant maximum value Z'_0 and its slope $-2\ \beta°$ at ω_0 the angular velocity of apparent resonance; also the quadrantal values ω_1 and ω_2, or their equivalents.* We thus obtain the total damping constant

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*See technique in Bibliography 17, p. 469.

$$\Delta = \frac{\omega_2 - \omega_1}{2} = \frac{r''}{2\,m} \qquad \text{hyps per sec.} \quad (42)$$

and

$$\omega_0 = \sqrt{s''/m} \qquad \text{rad. per sec.} \quad (43)$$

(2) The amplitude of displacement x_m over the poles at resonance is measured for the measuring current I. Hence

$$A = \frac{I\,Z'_0}{j\,x_0\,\omega_0} = \frac{I_m\,Z'_0}{j\,x_m\,\omega_0} = \frac{I\,Z_0'}{x_0} \qquad \text{abvolts per kine } \angle \quad (44)$$

Then from (40)

$$r'' = A^2/Z_0' \qquad \text{dynes per kine} \quad (45)$$

Hence by (42)

$$m = \frac{r''}{2\,\Delta} \qquad \text{gm.} \quad (46)$$

Also by (43)

$$s'' = m\,\omega_0^2 \qquad \text{dynes per cm.} \quad (47)$$

Having ascertained the value of the vector damped inductance $\mathfrak{L}$, at resonant impressed frequency, during the measurements of damped impedance, we find by (25)

$$p = A/\mathfrak{L} \qquad \text{absamp per cm.} \quad (48)$$

We can then compute the value of the resistance component r' of f_x by (29) at resonance

$$r' = \frac{p\,|A|}{\omega_0} \cdot \sin\,\beta \qquad \text{dynes per kine} \quad (49)$$

and hence r, neglecting changes in r' with frequency,

$$r = r'' - r' \qquad \text{dynes per kine} \quad (50)$$

Next s' can be computed from (30) and s found by the relation

$$s = s'' + s' \qquad \frac{\text{dynes}}{\text{cm.}} \quad (51)$$

The total number of turns N is supposed to be known, from which $\mathfrak{B}_0$ is obtainable through the bipolar relation

$$\mathfrak{B}_0 = 2\,\pi\,p\,N \qquad \text{gausses} \quad (52)$$

The equivalent number of turns N' for computing the displacement m. m. f. is

$$N' = p\,N \qquad \frac{\text{absamperes}}{\text{cm.}} \qquad (\mathbf{53})$$

assuming that N is a pure numeric. The quantities $p\,A$, $\mathfrak{F}_i$, ϕ_i and f_i are then easily found.

Motional Power. If a simple periodic m. m. f. of $\mathfrak{F} = 4\,\pi\,N\,I$ r. m. s. gilberts ∠ at the reference phase of I r. m. s. absamperes, acts upon a leackanceless magnetic circuit of vector permeance $\mathcal{P}$ maxwells per gilbert ∠, the vector magnetic flux thereby produced, neglecting harmonics, which are powerless, is

$$\phi = \mathfrak{F}\,\mathcal{P} \qquad \text{r. m. s. maxwells } \angle \quad (\mathbf{54})$$

The phase of the flux will have the slope $-\ \beta°$ of $\mathcal{P}$, with respect to the phase of the exciting current and m. m. f. The e. m. f. which will be induced in the coil will be

$$E = -\,j\,\omega\,N\,\phi = -\,j\,\omega\,N\,\mathfrak{F}\,\mathcal{P} \quad \text{r. m. s. abvolts } \angle \quad (\mathbf{55})$$

The power of this e. m. f., expressed electrically, is

$$P = E\,I = -\,j\,\omega\,N\,\phi\,I \qquad \text{abwatts } \angle \quad (\mathbf{56})$$

the slope of I being taken as zero.* The real component of P will be active power, expended thermally in the magnetic circuit, and the quadrature component will be reactive power expended in cyclically storing and releasing magnetic energy in the circuit. But (**56**) may be written**

$$P = -\,j\,\frac{\omega\,\mathfrak{F}\,\phi}{4\,\pi} = -\ j\,(f/2)\,\mathfrak{F}\,\phi \qquad \text{abwatts } \angle \quad (\mathbf{57})$$

where $\mathfrak{F}$ is taken as at standard phase, and ϕ has the lagging slope of $\beta°$ with respect thereto. The negative sign attached to the expressions in (**56**) and (**57**) indicates that the power is absorbed in the magnetic circuit.

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*Bibliography 7.

*The power exerted in a magnetic circuit by a simple alternating m. m. f. $\mathfrak{F}$ r. m. s gilberts, at zero slope, on a simple alternating flux ϕ r. m. s. maxwells ∠, is, in the C. G. S. system,

$$P = \frac{F}{4\,\pi}\cdot\frac{d\,\phi}{d\,t} \qquad \text{abwatts } \angle \quad (\mathbf{57a})$$

where the real component is average active power, and the imaginary component max. cyclic reactive power. Here $\frac{d\,\phi}{d\,t}$ corresponds to electric current.

In Fig. 20, the vector m. m. f. $\mathfrak{F}_i$ is drawn to the same reference phase as I. The flux ϕ_i, thereby produced, with the diaphragm damped, is indicated as lagging $\beta°$ behind $\mathfrak{F}_i$. The induced e. m. f. E, lags $90° + \beta°$ behind $\mathfrak{F}_i$. The vector power $E\,I$, taken with I as of zero slope, is $O\,a$. Its real component, $O\,b$, is dissipated. The undissipated or reactive component is $b\,a$.

In Fig. 21, the r. m. s. m. m. f. and r. m. s. flux are represented without reference to e. m. fs. Their vector product $\mathfrak{F}_i\,\phi_i$, taking $\mathfrak{F}_i$ as of standard phase, would be along the dotted line $O\,c$. Taking $-f/2$ times this product, as called for in (**57**), we obtain, to a power scale, the vector $O\,d$, Fig. 22.

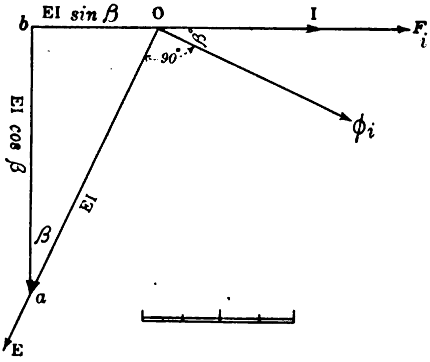

FIG. 20—DIAGRAM OF A R.M.S. M.M.F., THE R. M. S. FLUX THEREBY PRODUCED, THE CONSEQUENT E. M. F. AND THE VECTOR POWER

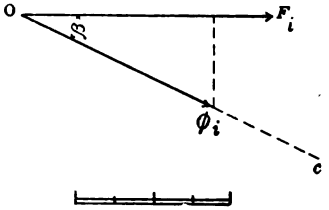

FIG. 21—FUNDAMENTAL RELATIONS OF POWER IN A MAGNETIC CIRCUIT CARRYING A R. M. S. FLUX $\phi\mathfrak{F}_i$, UNDER AN IMPRESSED R. M. S., M. M. F.

The cosine product of $f\;\mathfrak{F}_i/2$ and ϕ_i is reactive magnetic power, and the sine product, or vector product, active power liberated from the magnetic circuit. These conditions are opposite to those in the alternating electric circuit, where the cosine product is active and the sine product reactive electric power. In order to interpret this vector magnetic-circuit power correctly, we may rotate the axis $O\,X$ of reference, through $-90°$, into the position $O\,A$. The component $Oc = -(f/2)\;\mathfrak{F}_i\;|\phi_i|\sin\beta$ is then the average active power, absorbed by the magnetic circuit, and liberated from it, usually as heat; while the reactive component $O\,b = -(f/2)\;\mathfrak{F}_i\;|\phi_i|\cos\beta$ is power absorbed in storing and releasing magnetic energy.

If, however, we consider the vector power delivered by the electric circuit to the magnetic circuit, it will have the opposite sign to $O\,d$, or will be $O\,d$ reversed, and equal to the vector $O\,d'$, whose components are $O\,c' = +\ (f/2)\ \mathfrak{F}_i\,|\phi_i|\sin\beta$, liberated active power and $O\,b' = +\ (f/2)\ \mathfrak{F}_i\,|\phi_i|\cos\beta$ reactive power engaged in storage.

In Fig. 23, we have the vector magnetic power delivered from the electric circuit with the diaphragm damped. The real component is $O\,a'$ and the reactive component $a'\,a$.

When the diaphragm is free, we have the displacement m. m. f. $\mathfrak{F}_x$ and its flux ϕ_x introduced into the magnetic circuit, as shown in Fig. 24. The resultant of these two m. m. fs. is $\mathfrak{F}$, and that of the two corresponding fluxes is ϕ. This magnetic-circuit vector diagram bears a close resemblance to the electric-circuit vector diagram for the simple case of an alternator driving a synchronous motor through the impedance of a connecting circuit. The m. m. fs. of Fig. 24 then correspond to e. m. fs., flux-frequencies to currents, and their respective permeance vector ratios to admittance ratios. We have

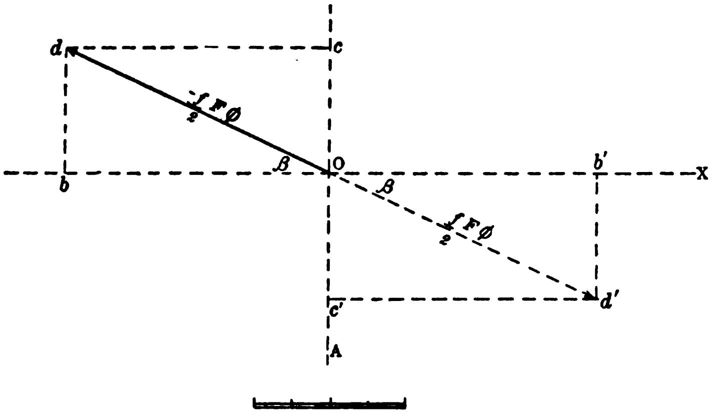

FIG. 22—POWER RECEIVED FROM AND DELIVERED TO A MAGNETIC CIRCUIT CARRYING A R.M.S. FLUX ϕ LAGGING $\beta°$ BEHIND AN IMPRESSED R. M. S. M. M. F. $\mathfrak{F}_i$ AT FREQUENCY f CYCLES PER SEC.

$$\mathfrak{F}_i + \mathfrak{F}_x = \mathfrak{F} \qquad \text{r. m. s. gilberts} \angle \quad \textbf{(58)}$$

If we multiply this equation by the vector resultant flux ϕ, considered for that purpose as of standard phase, we obtain

$$(f/2)\ \mathfrak{F}_i\,\phi + (f/2)\ \mathfrak{F}_x\,\phi = (f/2)\ \mathfrak{F}\,\phi \quad \text{abwatts} \angle \quad \textbf{(59)}$$

The first term is here the vector power input P_i'' delivered to the magnetic circuit by the exciting current. The second term, reversed in sign, is the vector power P_m liberated from the magnetic circuit into pure mechanical power of the diaphragm, both active and reactive, and corresponding to vector mechanical power given to a synchronous motor in an electric circuit. The term $(f/2)\mathfrak{F}\,\phi$ is the vector power P_r'' expended thermally within the magnetic circuit in overcoming its reluctance. The equation (59) may therefore be written

$$P_i'' - P_m = P_r'' \qquad \text{abwatts} \angle \quad (60)$$

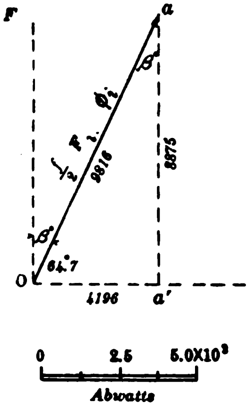

FIG. 23—POWER DELIVERED TO MAGNETIC CIRCUIT AT 1028 CYCLES PER SEC.—DIAPHRAGM DAMPED

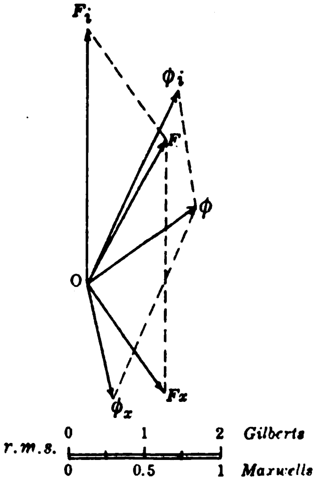

FIG. 24—DIAGRAM OF M. M. F' AND FLUXES IN MAGNETIC CIRCUIT —DIAPHRAGM FREE

In the instrument referred to, these vector values at 1028~ were as shown in Fig. 25, where $O\,b$ is the magnetic input of $P_i'' = 6438 \angle 36^\circ.8$ abwatts, with an active component of 5156 abwatts, liberated both in heat and in mechanical power, and a reactive component of 3856 abwatts, engaged in the reactive storage of magnetic energy. P_m or the vector $O\,a$, is the power expended on the diaphragm mechanically, 3349 $\angle 0.^\circ 7$ abwatts, almost entirely in the active form, nearly 3349 abwatts being developed in vibratory motion $\dot{x}^2 r$, against mechanical resistance r and 40 abwatts in reactive mechanical power; *i. e.*, power consumed in exchanging potential energy cyclically from the elastic to the inertia type. The vector $a\,b$ or P_r'' is the power expended in the magnetic conducting circuit by the total flux ϕ in overcoming the vector reluctance $\mathcal{R}$ of that circuit. At this frequency, it was 4199 $\underline{/64^{\circ}}.7$ abwatts, with a real component *a b′* of 1795 abwatts, expended thermally in hysteresis and eddy currents. The reactive component *b′ b* of 3797 abwatts is expended in maintaining the activity of cyclically storing and releasing magnetic energy of the type $\frac{\mathcal{B}^2}{8\,\pi\,\mu}$ ergs per cu. cm. in the magnetic conducting circuit.

When the diaphragm is damped, the magnetic circuit conditions are shown in Figs. 21 and 23. Here the magnetic input at 1028 ∼ is 9816 $\underline{/64^{\circ}}.7$ abwatts, with no counter m. m. f. of motion. The active component *O a′* is 4196 abwatts, expended entirely in heat leaving the circuit. The reactive component is 8875 abwatts, engaged in maintaining the cyclic storage and release of magnetic energy.

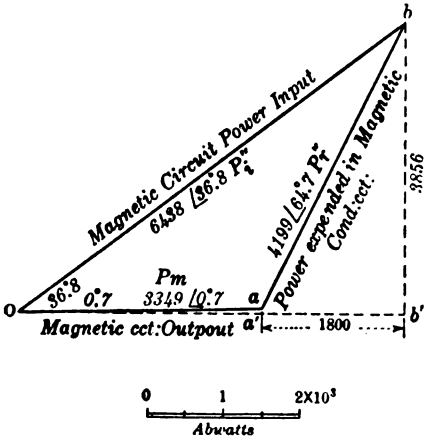
b
Magnetic Circuit Power Input
6438 $\underline{/36^{\circ}.8}$ P_i''
4199 $\underline{/64^{\circ}.7}$ P_r''
Power expended in Magnetic Cond: cct.
3856
O
36°.8
0°.7
Pm
3349 $\underline{/0^{\circ}.7}$
a
Magnetic cct: Outpout
a′
1800
b′
0
1
2X10³
Abwatts

FIG. 25—MAGNETIC CIRCUIT POWER DIAGRAM—DIAPHRAGM FREE

The motional magnetic power diagram is obtained as in Fig. 26 by subtracting the magnetic power input damped P_i, from the magnetic power input free, P_i''. The difference, at the frequency of 1028 ∼, is 5108 $\overline{\diagdown}$ 79.°2 abwatts, with an active component of 957 abwatts, representing an increase of the power taken from the electric supply circuit and a negative reactive component of 5018 abwatts, representing a diminution in magnetic power of storage.

It should be observed that the active component *O c* = 957 abwatts is much smaller than the power $P_m = 3349$ abwatts, (Fig. 25) put into the diaphragm. The difference of 2392 active abwatts is diverted from the power previously wasted in the magnetic circuit of 4196, Fig. 23, only 1800 abwatts (*a b′* Fig. 25), being wasted thermally when the diaphragm is freed. Consequently, the motional power diagram does not reveal on its real axis all the power delivered to the diaphragm; but only that part which is supplied from the electric circuit. The remainder has to be made up from power saved in hysteretic and eddy loss, due to the reduction in magnetic flux by the motional counter m. m. f., especially towards higher frequencies.

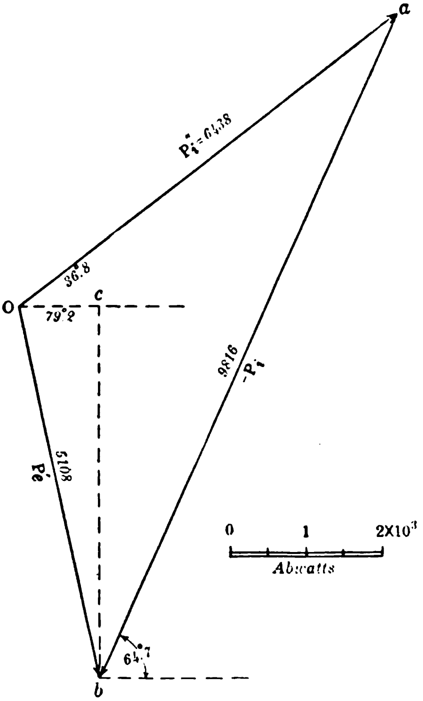

FIG. 26—DIAGRAM OF MOTIONAL POWER IN MAGNETIC CIRCUIT—DIAPHRAGM FREE

Turning to Fig. 27, the motional power diagram, the circular locus there represented may be considered as the motional impedance circle of Fig. 10, changed in scale, however, for convenience, in order to permit powers to be read off it. If, however, a fractional scale of power is accepted, the motional impedance circle may be interpreted directly as a motional power diagram. In Fig. 27, *O a* is the vector corresponding in phase to the motional impedance vector at the frequency considered, in this case 1028 ∼. There are three pairs of co-

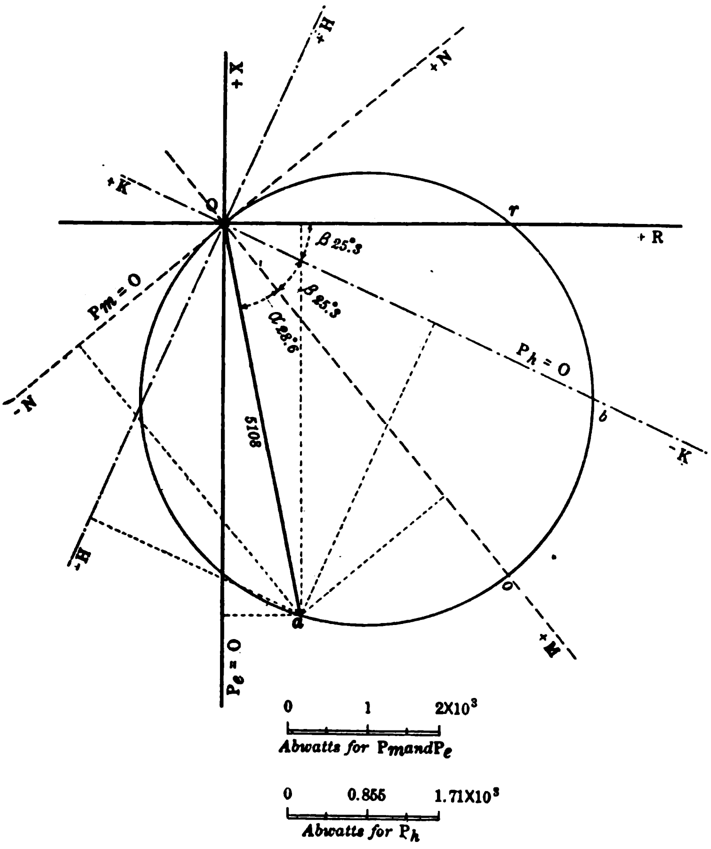

FIG. 27—MOTIONAL POWER DIAGRAM

ordinate axes; namely (1) *O R*, at standard phase, for the electric circuit power, and *O X* its perpendicular, (2) *O H*, inclined at $-\ \beta°$ from *O X*, and its perpendicular *O K*, for components of hysteretic loss in the magnetic circuit, and (3) *O M*, at a slope of $-2\ \beta°$ with *O R*, and its perpendicular *O N*, for mechanical power of vibration in the diaphragm.

At any vector motional power $O\,a$, we have the following vector relation

$$P_m'' = P_e' - P_h' \cdot 2 \sin \beta \qquad \text{abwatts } \angle \quad (61)$$

Or, in language, the vector mechanical power P_m'', as read to coordinates $O\,M$, $O\,N$, is equal to the electrically delivered vector power P_e', read to coordinates $O\,R$, $O\,X$, less the hysteretic power P_h', read to coordinates $O\,H$, $O\,K$, multiplied by the coefficient $2 \sin \beta$, which in this case is 0.855: Moreover, this equation is true not only for these quantities as vectors; but also for their respective active components,

$$P_{ma}'' = P_{ea}' - P_{ha}' \cdot 2 \sin \beta \qquad \text{active abwatts} \quad (62)$$

and likewise for the reactive components

$$P_{mr}'' = P_{er}' - P_{hr}' \cdot 2 \sin \beta \qquad \text{reactive abwatts} \quad (63)$$

These propositions, which apply here to the energetics of a telephone receiver, for the particular case of β as the angle separating the systems of coordinates, are true in a general geometric sense for any plane vector, measured to three such sets of coordinates, without restriction of the value of β, and also without restriction as to the locus of the radius vector. This proposition is discussed in the Appendix.

In Fig. 27, we assume a knowledge of Z'_0 absohms ∠, as well as I r. m. s. absamperes the testing current strength, at standard phase. The power expended in this impedance will be $I^2\,Z_0'$ abwatts at the same slope as that of Z_0'. In the case considered, $I = 2.04 \times 10^{-4}$ r. m. s. absamperes, and $Z_0' = 140 \times 10^9$ ⦣ 50°.6 absohms. The vector power is therefore $(2.04)^2 \times 1.4 \times 10^3 = 5827$ ⦣ 50.°6 abwatts. This vector $O\,o$ is laid off in Fig. 27, to scale, as the diameter of the motional power circle $O\,r\,o\,a$. At any assigned impressed angular velocity ω, the angle of the corresponding radius vector with respect to the diameter $O\,o$ is

$$\alpha = \tan^{-1}\left(\frac{m\,\omega - s''/\omega}{r''}\right) \qquad \text{degrees lag} \quad (64)$$

In the case considered, with $f = 1028 \sim$, and $\omega = 6460$, $m\,\omega = 5827$, $s''/\omega = 5681$, $r'' = 268$; so that

$$\alpha = \tan^{-1} 0.545 = 28.^\circ 6.$$

The vector position $O\,a$, corresponding to $1028 \sim$ can thus be laid down in the circle. Its length is 5108 abwatts. With respect to the $R\,X$ coordinates it is $5108 \nwarrow 79.^\circ 2$. It is $5108 \nwarrow 28.^\circ 6$ to $M\,N$, and $5108 \nwarrow 143.^\circ 9$ to $H\,K$. Here the electrical vector is $5108 \nwarrow 79.^\circ 2$ abwatts, the mechanical vector $5108 \nwarrow 28.^\circ 6$, and the hysteretic vector $P_h = P_h' \cdot 2 \sin\beta$

$$= 5108 \nwarrow 143.^\circ 9 \times 2 \sin 25.^\circ 3 = 4369 \nwarrow 143.^\circ 9.$$

The proposition of (**61**) states the mechanical power of $5108 \nwarrow 28.^\circ 6$, is equal to the electrical power of $5108 \nwarrow 79.^\circ 2$, minus the hysteretic power $4369 \nwarrow 143.^\circ 9$. Moreover, the active mechanical power of vibration, $x^2 r''$ is the $O\,M$ component of $O\,a$, or 4484 abwatts. This is made up of the active electric power component $I^2 R'$, as measured on the $O\,R$ axis, of 957 abwatts, minus the active hysteretic component along the H axis, or $- (- 3537) = + 3537$ abwatts. The mechanical power is therefore mainly supplied by saving in hysteresis loss, and only partly supplied by assistance from the electric circuit. Similarly, the reactive mechanical power $j\,x^2\,(m\,\omega - s''/\omega)$ is the $O\,N$ component of $O\,a$, and measures $-j\,2445$ abwatts. This is equal to the reactive electric component $j\,I^2\,X'$ along $O\,X$ or $-j\,5018$ less the hysteretic component measured to its own scale along $O\,K = - (-j\,2591) = j\,2591$ abwatts.

Proceeding in the above manner, the power put into mechanical vibration of the diaphragm can be read off the power circle at any assigned frequency, and its component sources, electrical and hysteretic, determined either graphically or by computation. It will be evident that for frequencies below that of the vector $O\,b$, β° behind $O\,R$, the hysteretic active power is positive. This means that the hysteretic loss is increased at these frequencies, so that the electric circuit has to supply not only all the mechanical vibration power, but also the extra hysteresis and eddy loss due to increased magnetic flux. At the frequency of $O\,b$, there is no additional hysteretic loss, because the flux in the magnetic circuit has the same size, with the diaphragm either damped or free. At this particular frequency, all the active mechanical power is supplied directly from the electric circuit. At frequencies above that of $O\,b$, the active mechanical power is partly supplied by hysteresis saving. At the vector point c, where the circle cuts the reactance axis, there will be no extra power supplied by the circuit to maintain the mechanical output of the diaphragm; but all of this power will be paid for by saving in hysteresis loss, when the diaphragm is released.

The total active mechanical power developed in the diaphragm will be

$$P_m'' = \dot{x}^2 (r + r') = \dot{x}^2 r'' \qquad \text{abwatts} \quad (65)$$

and the active power put into vibration

$$P_m = \dot{x}^2 r \qquad \text{abwatts} \quad (66)$$

Similarly, the active power put into motional hysteresis loss,

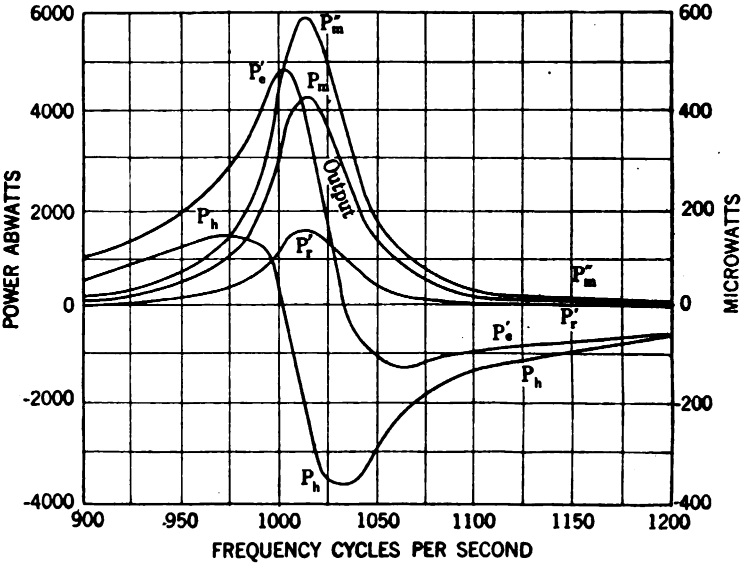

FIG. 28—MAGNETIC CIRCUIT MOTIONAL POWER DISBTRIBUTION AT DIFFERENT FREQUENCIES. P_m'' GROSS MECHANICAL ACTIVE OUTPUT P_e' ACTIVE ELECTRIC POWER INCREASES P_h CHANGE OF HYSTERETIC POWER. P_r' ACTIVE MECHANICAL POWER EXPENDED AGAINST r' IN DISPLACEMENT. P_m NET ACTIVE MECHANICAL OUTPUT FREE. $P_m'' = P_e' - P_h = P_r' + P_m$.

by reason of the vibration of the diaphragm in the magnetic field will be

$$P_r' = \dot{x}^2 r' \qquad \text{abwatts} \quad (67)$$

The mechanical efficiency of the diaphragm, as a motor, at resonance, is therefore

$$\eta_0 = \frac{r}{r''} = \frac{r}{r + r'} \qquad \text{numeric} \quad (68)$$

In the case considered, $\eta_0 = 0.74$.

Strictly speaking, according to our theory, r' is a function of ω, see (**29**), but unless the resonance is very blunt, the changes in r' and in η, with change in frequency, are not likely to be important.

Fig. 28 shows the distribution of the various active powers, in the instrument considered, over a range of frequency from 900 ~ to 1200 ~. Here $P_m = \dot{x}^2 r$ is the active mechanical power output in sound and in overcoming internal mechanical bending friction of the diaphragm. $P_r' = \dot{x}^2 r'$ is active mechanical power expended in the magnetic circuit in hysteresis and in eddies, by reason of the vibration of the diaphragm in the permanent magnetic field. $P_m'' = \dot{x}^2 r'' = \dot{x}^2 (r + r') = P_m + P_r'$ is the total active mechanical output of the diaphragm. P_e' is the extra active electric power taken from the electric circuit and put into mechanical vibration when the diaphragm is freed. The saving of active damped power put into the magnetic circuit when the diaphragm is freed is $- P_h$. Consequently

$$P_m'' = P_e' - P_h.$$

The following tabular statement gives the computed analysis of the constants of the particular instrument considered, partly taken from the Kennelly-Affel paper of 1915, already referred to, and partly as developed in this analysis:

TABLE OF NUMERICAL DATA CONCERNING ANALYZED RECEIVER

MECHANICAL	
Area of each pole, cm × cm.	1.14 × 0.199
Distance Separating poles, cm.	0.686
External diam. of diaphragm, cm.	5.52
Diameter of clamping circle, cm.	5.0
Thickness of diaphragm over japan cm.	0.031
Weight of diaphragm, gm.	4.397
Number of turns including both spools.	1300
ELECTRICAL	
D-c. Res. at 20 deg. cent. absohms R_1	86.7×10^9
Inductance at Resonant Frequency $\mathcal{L}_0$ abhenries.	3.65×10^7
Current through receiver I r. m. s. absamp.	2.04×10^{-4}
Resonant Frequency apparent, f_0 cycles per sec.	1015
Resonant angular vel: ω_0 radians per sec.	6378
Motional impedance circle diameter Z_0' absohm.	140×10^9
Slope of Permeance at resonant frequency β. degrees	−25°. 3

Max. amplitude of vibration at resonance x_m cm	10.35×10^{-4}
Effective cyclic amplitude vibration at resonance x_0 cm.	7.32×10^{-4}
Max. cyclic velocity at resonance $\dot{x}_0$ r. m. s. cm. per sec or kines	4.666
Quadrantal angular velocities ω_1, ω_2 radians/sec..	6227 6532
Total decrement Δ hyps. per sec.	149
Force factor A dynes /absampere or abvolts/kine.	6.12×10^{6} ⦣ 25.°3
Total mechanical resistance r'' dynes/kine.	268
Equivalent mass in grams.	0.902
Total stiffness coefficient s'' dynes/cm.	36.7×10^{6}

RECOMPUTED ELECTROMAGNETIC DATA

Ratio of numbers of turns p absampere/cm.	0.168
Mechanical resistance of magnetic reaction r' dynes/kine	68.8
Pure mechanical resistance r dynes/kine.	199
Stiffness coefficient of magnetic reaction s' dynes/cm.	0.928×10^{6}
Pure mechanical stiffness coefficient s dynes/cm.	37.63×10^{6}
Equivalent number of turns per cm. displacement N' gilberts/cm.	218
Normal mean polar flux density $\mathcal{B}_0$ gausses.	1369
Normal total polar flux Φ_0 maxwells/pole	311.0
Equivalent permanent magnetic reluctance $\mathcal{R}_0$ oersteds	0.582 ∠ 25.°3
Equivalent permanent magnetic permeance $\mathcal{P}_0$ $(\text{oersteds})^{-1}$	1.718 ⦣ 25.°3
Equivalent permanent m. m. f. gilberts.	181
M. M. F. of testing current (2.04×10^{-4}) r. m. s. gilberts $\mathfrak{F}_i$.	3.334 ∠ 0°
Flux in magnetic circuit due to current ϕ_i r. m. s. maxwells	5.73 ∠ 25.°3
Mechanical force due to current I f_i, r. m. s. dynes, $v\,m\,f$	1249 ⦣ 25.°3
Magnetic power input at 1028 ~ with current I, P_i abwatts,	9816 ∠ 64.°7 $= 4196 + j\,8875$
Total mechanical impedance at $f = 1028$, z' dynes/kine	305.2 ∠ 28.°6
Mechanical velocity at $f = 1028$. $\dot{x}$. r.m.s. cm/sec.	4.091 ∠ 53.°9
Cyclic mechanical displacement at $f = 1028$. x r. m. s. cm.	6.332×10^{-4} ⦣ 143.°9
M. M. F. due to displacement, at $f = 1028$ and for current I, $\mathfrak{F}_x$ r. m. s. gilberts.	1.735 ⦣ 143.°9
Resultant m. m. f., at $f = 1028$. $\mathfrak{F}$ r. m. s. gilberts	2.174 ∠ 28°
Flux due to displacement, at $f = 1028$. ϕ_x r.m.s. maxwells	2.980 ⦣ 169.°2

Resultant flux at $f = 1028$. ϕ r. m. s. maxwells. $3.757 \measuredangle\!\!\!\diagdown\; 53.^\circ 2$

Magnetic input diaphragm free, at $f = 1028$.

P_i'' abwatts .... $6438 \angle 36.^\circ 8$
$= 5156 + j\,3856$

Free magnetic power, or total power absorbed in magnetic circuit, at $f = 1028 \sim$, abwatts $\angle\ P_r'' = 4199 \angle 64.^\circ 7$
$= 1795 + j\,3797$

Mechanical output power of diaphragm, P_m at 1028 $\sim$ abwatts $\angle$ .... $= 3349 \angle 0.^\circ 7$
$= 3349 + j\,40$

Total mechanical power of diaphragm at 1028 $\sim$ P_m'' abwatts $\angle = 5108 \measuredangle\!\!\!\diagdown\; 28.^\circ 6 = 4484 - j\,2445$

Motional electric power of diaphragm at 1028 $\sim$ P_e' abwatts $\angle = 5108 \measuredangle\!\!\!\diagdown\; 79.^\circ 2 = 957 - j\,5018$

Hysteretic power at 1028 $\sim$ P_h abwatts $\angle = 5108 \times 0.855 = 4369 \measuredangle\!\!\!\diagdown\; 143.^\circ 9 = -\,3537 - j\,2591$

Mechanical efficiency of diaphragm at apparent resonance, η_0 numeric $= 0.74$

Net efficiency of receiver, freed, and at apparent resonance numeric, $= 0.4$

Maximum motional impedance per unit of continuous-current resistance Z_0'/R_1 numeric $\angle = 2.04 \measuredangle\!\!\!\diagdown\; 50.^\circ 6$

Force factor per root of continuous-current res.

$$A/\sqrt{R}\ \frac{\text{dynes}\ \sqrt{\text{absohms}}}{\text{abvolts}}\ \angle = 23.36 \measuredangle\!\!\!\diagdown\; 25.^\circ 3$$

Effect of a Changing the Number of Turns in Receiver of given Winding Space. If the windings of a given receiver are allowed to occupy a definite constant volume, and also if the ratio of bare to covered wire diameter is kept constant over the range of wire diameters selected for the winding, so that the same volume and weight of copper will exist no matter what the size of wire; then it is evident that if we reduce the wire diameter one-half, the number of turns N will be quadrupled and the d-c. resistance R_1, at constant temperature, increased sixteen fold. The effect of this will be to increase N, A, $\mathcal{F}_i$, and ϕ_i, 4 times, leaving $\mathcal{F}_0$, $\mathcal{B}_0$, $\mathcal{P}$, and β, unchanged. The quantities $\mathcal{L}$, Z, Z_0', P_e, and P_{m0}, will be all increased 16 times, (neglecting variations in r') or in direct proportion to the resistance. Consequently the ratio of active mechanical power output $\dot{x}^2\, r/I^2\, R_1$, where R_1 is the d-c. resistance of the instrument, will remain substantially unchanged for all values of R_1 within the range for which the copper in the winding space remains constant. On this theory, changing the winding of a receiver, other things remaining the same, increases the mechanical output at resonance in proportion to the resistance, for a fixed exciting current strength, but for a given amount of $I^2 R_1$ power loss in the winding, this mechanical power output remains substantially constant.

Since Z_0' the maximum or diametral value of the vector motional impedance increases, according to this theory, directly with the d-c. resistance of the winding, different receivers should have their diametral impedances Z_0' reduced to a common basis of comparison by taking the ratio Z_0'/R_1. The sensitiveness of a receiver is proportionate to this ratio. The ratio is independent of the strength I of the testing current. An instrument of large diametral impedance per unit of d-c. resistance is therefore an instrument of inherently large electromagnetic sensitivity, no matter what the resistance of the winding may be. This ratio calls for no other measurements than that of the motional impedance circle or the essential sector thereof, and the d-c. resistance at normal temperature.

Similarly, the force factor A should be divided by $\sqrt{R_1}$, in order to bring it to a common basis of comparison among various receivers.

It should be observed that the diametral or maximum size of the motional impedance Z_0' is not produced at the frequency of strict mechanical resonance of the diaphragm. True mechanical resonance is produced when the angular velocity is such that the mass reactance $m\ \omega$ is numerically equal to the elastic reactance s/ω. In the motional-impedance circle, however, the apparent resonance and diametral impedance are produced when $m\ \omega = \dfrac{s''}{\omega} = \dfrac{s - s'}{\omega}$. The fictitious component s', due to the displacement flux, thus slightly lowers the apparent resonance, or causes the maximum velocity, displacement, and impedance to occur at a frequency a little lower than that of true mechanical resonance. In the case considered, mechanical resonance would be produced at $\omega_0 = \sqrt{s/m} = \sqrt{37.63 \times 10^6/0.902} = 6459$ radians per sec.; corresponding to 1028$\sim$; whereas the apparent resonance would be produced at $\omega''_0 = \sqrt{s''/m} = \sqrt{36.7 \times 10^6/0.902} = 6379$, corresponding to 1015$\sim$. This displacement of resonance must occur in the motional impedance circle, whatever method of including the effects of the displacement flux φ_x is adopted. Apparent resonance occurs at the frequency of mechanical resonance as modified by magnetic reaction, which acts in such a manner as to reduce the stiffness coefficient of the diaphragm. The angle of displacement $h\,b\,o$ in the motional impedance circle, Fig. 10, between the vector of true mechanical resonance and apparent resonance, is equal to the angle α between ϕ and ϕ_i at the angular velocity ω_0' of true mechanical resonance; because at ω_0' the velocity $\dot{x}$ is in phase with the resultant flux ϕ.

A bibliography of the subject, without pretensions as to completeness, is appended, in so far as relates to the motional-impedance aspect of telephone-receiver theory.

It may be noted that the maximum mechanical output $\dot{x}_0^2\,r''$ at apparent resonance is entirely active power, and is numerically equal to $I^2\,|Z_0'|$ abwatts or the square of the testing current multiplied by the size of the diametral impedance. This constitutes a simple method of determining the maximum mechanical output of the diaphragm, including frictions and hysteretic loss due to vibration. The gross efficiency of the receiver at apparent resonance is therefore $\frac{I^2\,|Z_0'|}{I^2\,R_0''} = \frac{|Z_0'|}{R_0''}$.

In this case, this efficiency reaches $\frac{140}{257.3} = 0.544$. This must be multiplied by the $\eta_0 = 0.74$ to give the net efficiency of the receiver at apparent resonance of 0.40. This is the ratio of active mechanical output of the diaphragm, including internal frictions and acoustic delivery, to the active electric power consumed at terminals, with the diaphragm free. With the receiver pressed against the ear, the condition is intermediate between damped and free.

SUMMARY OF RESULTS

1. The theory presented in the earlier papers mentioned in the bibliography were lacking in not taking into account the m. m. f. and flux, of diaphragm vibratory displacement in the magnetic field.

2. The present theory purports to include the above mentioned elements, under the form of an apparent increment r' in mechanical resistance, and an apparent diminution s' in the stiffness coefficient, the latter being independent of the frequency, but the former varying inversely as the frequency.

3. The effect of r' is to introduce a slight distortion of the motional impedance and power diagrams from the strictly circular locus, assuming the force-factor A and other constants

to remain substantially the same at all frequencies; but the distortion is not serious from a practical standpoint.

4. The m. m. f. of vibratory displacement may be expressed in terms of a coefficient N', a fictitious number of turns. The ratio p of N'/N is a constant of the instrument.

5. The depression of the motional-impedance circle diameter is 2 $\beta°$ where $\beta°$ is the lag angle of the damped magnetic flux behind the exciting current.

6. The power analysis depends directly upon the m. m. f. and flux diagram, without any necessary reference to the e. m. fs. produced. The power in the magnetic circuit is then found to be similar to the power in a simple alternating-current circuit, containing an alternator, a synchronous motor, and a simple connecting impedance.

7. The observed motional impedance circle may be converted into a corresponding motional power circle, by a suitable alteration in scale of linear dimensions. By introducing three sets of coordinate axes, mutually displaced by $\beta°$, the power output P''_m, can be read off in terms of the electric power input P'_e, and the hysteretic power input P_h. The same relation holds for active and for reactive components.

8. At the slope $-\ \beta°$ in the power circle, the mechanical power is all electric. At the slope $-\ 90°$, it is all hysteretic.

9. The active power mechanically expended in the magnetic circuit by the diaphragm as a motor, against hysteresis and eddy currents $\dot{x}^2 r'$, can be separated from that expended against friction and air resistance $\dot{x}^2 r$. The mechanical efficiency is

$\dfrac{r}{r + r'}$, which varies somewhat with the frequency. It tends to increase slightly with frequency, according to this theory.

10. The behavior of a particular instrument analysed some years ago in a preceding paper is investigated in detail, at a particular frequency, in accordance with the theory.

11. The gross efficiency of a receiver at apparent resonance is $\dfrac{|Z'_0|}{R''_0}$ or the ratio of the motional impedance diameter to the apparent resistance of the instrument at this frequency with the diaphragm free.

Appendix

Proposition that the Plane Vector

$$|\rho|\,\backslash\overline{\alpha} = |\rho|\,2\,\backslash\overline{\beta+\alpha} \qquad -2\sin\beta\,|\rho|\,\backslash\overline{90^\circ+\alpha^\circ+\beta}$$

In Fig. 29, *O A* is a planevector, or geometrical complex quantity of any convenient size ρ, taken at standard phase, or zero slope. It may be denoted by ρ_A · *O B* is a similar plane vector of the same size, distinguished by the symbol ρ_B. Its slope is $-2\ \beta^\circ$. *O c* is a vector denoted by ρ_c of size ρ and drawn perpendicular to *O d*, the bisector of the angle *A O B*.

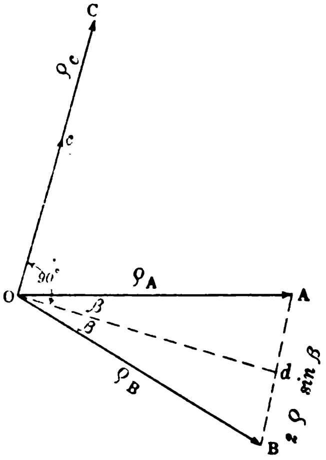

FIG. 29

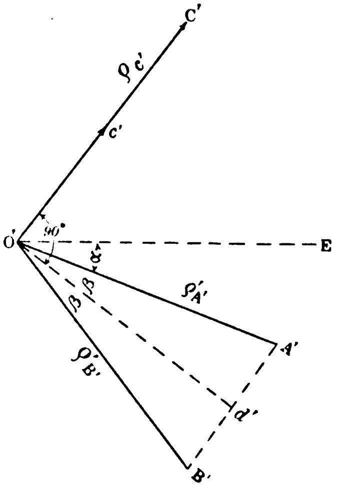

FIG. 30

Then, because *B A* expressed vectorially is $|\rho|\,2\sin\beta\,/\underline{90^\circ-\beta}$ and is equal to the vector *O c*, we have the vector relation

$$\rho_B = \rho_A - 2\sin\beta\cdot\rho_c \qquad \text{length units } \angle \quad (\mathbf{69})$$

If now, as in Fig. 30, we rotate the whole vector system in the plane of reference through the angle $-\ \alpha^\circ$ with respect to *O E*, a fixed line of reference, the effect will be the same as though the vector system remained fixed in the plane; but the line of reference, *O E* was rotated through an angle of $+\ \alpha$. This rotation of a reference line cannot, however, affect the vector relation expressed in (**69**) when those vectors are taken to the new reference line.

But the three vectors of (**69**) may be regarded as one and the same vector ρ, Fig. 31, expressed each with respect to three initial lines $O''\,m$, $O''\,e$, and $O''\,h$, and then denoted by ρ_m, ρ_e and ρ_h respectively. Thus in Fig. 32,

$$|\rho_m|\,\backslash\overline{\alpha} = |\rho_e|\,\backslash\overline{2\,\beta + \alpha} - |\rho_h|\,2\sin\,\beta\,\backslash\overline{90^\circ + \alpha + \beta} \quad \text{length units } \angle \quad (70)$$

Since this relation holds for the vectors themselves, it must also hold for their real components, and for their imaginary components respectively.

The power circle of Fig. 27, corresponds to Fig. 31; while

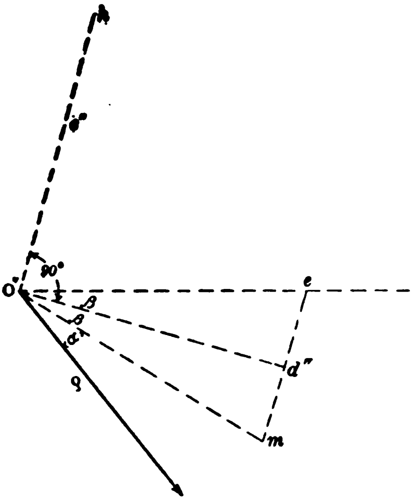

Fig. 31

the interpretation of (**62**) and (**63**) are referable to the construction of Fig. 32.

Referring to Fig. 24, in the analogy of a simple a-c. circuit in which a generator of $\mathfrak{F}_i$ r. m. s. abvolts terminal e. m. f. supplies an external circuit of fixed admittance $\mathcal{P}$ mhos ∠, with a current of ϕ_i r. m. s. absamperes. To the condition of diaphragm damped, corresponds the analogous condition of zero c. e. m. f. in the synchronous motor. To the condition of diaphragm free, corresponds the analogous condition of e. m. f. $\mathfrak{F}_x$ r. m. s. abvolts in the synchronous motor armature, which would produce the current of ϕ_x r. m. s. absamperes if operating independently in the circuit, at assumed constant frequency.

The vector change in electric power P'_e given by the alternator to the circuit when the diaphragm is suddenly freed, will be the power exerted by the e. m. f. $\mathfrak{F}_i$ on the current ϕ_x. The vector mechanical power P_m'' given to the motor by the current ϕ_i will be the power of ϕ_i on $\mathfrak{F}_x$.

Converting these electric powers into their analogous magnetic powers, and remembering that in the magnetic circuit a vector a-c. m. m. f. $|\mathfrak{F}| \angle \gamma°$ r. m. s. gilberts, producing a vector alternating flux $|\phi| \angle 0°$ r. m. s. maxwells, develops a vector power in the magnetic circuit of $|(f/2)\ \mathfrak{F}\ \phi| \angle\ 90° - \gamma°$ abwatts, of which the real part is average active power, and the imaginary part is maximum cyclic reactive power, we have

$$P'_e = |(f/2)\ \mathfrak{F}_i\ \phi_x| \angle\ 90° - (90° + \alpha + 2\ \beta)$$
$$= |(f/2)\ \mathfrak{F}_i\ \phi_x| \overline{\diagdown} \alpha + 2\ \beta = |(f/2)\ \mathfrak{F}_x\ \phi_i| \overline{\diagdown}\ \alpha + 2\ \beta \quad \text{abwatts} \angle \quad (71)$$

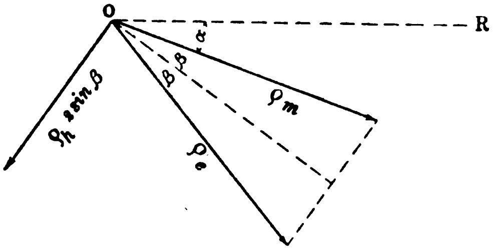

Fig. 32

where $90° + \alpha$ is the angle between ϕ_i and $\mathfrak{F}_x$. This vector power has a circular locus, because $|(f/2)\ \mathfrak{F}_x| \overline{\diagdown} \alpha$ has a circular locus.

Also

$$P_m'' = |(f/2)\mathfrak{F}_x\phi_i| \angle 90° - (90° + \alpha) = |(f/2)\mathfrak{F}_x\phi_i| \overline{\diagdown} \alpha \quad \text{abwatts} \angle \quad (72)$$

This vector mechanical power must also have a circular locus under varying frequency.

Consequently,

$$P_e' - P_m'' = |(f/2)\ \mathfrak{F}_x\ \phi_i| \overline{\diagdown} \alpha + 2\ \beta - |(f/2)\ \mathfrak{F}_2\ \phi_i| \overline{\diagdown} \alpha \quad \text{abwatts} \angle \quad (73)$$

and this by (70) is

$$P_h = |(f/2)\ \mathfrak{F}_x\ \phi_i| \cdot 2 \sin\ \beta \overline{\diagdown} 90° + \alpha + \beta \quad \text{abwatts} \angle \quad (74)$$

a vector hysteretic power having also a circular locus.

LIST OF SYMBOLS EMPLOYED

For simplicity of numerical treatment and universality of application, the units employed are those of the C. G. S. magnetic system.

A	force factor (dynes per absampere ∠* or abvolts per kine ∠)
α	angle of mechanical effective impedance; *i. e.*, mechanical impedance including magnetic displacement reaction (degrees)
$\mathcal{B}_0$	magnetic flux density in the airgaps due to permanent magnet (gausses)
$\mathcal{B}_i$	r. m. s. magnetic flux density due to current (r. m. s. gausses ∠)
$\mathcal{B}$	instantaneous alternating flux (gausses)
β	mean angle of lag between magnetic flux and m. m. f. (degrees)
C	capacitance of a condenser (farads or abfarads)
$\Delta = \frac{r''}{2m}$	total apparent damping constant of a diaphragm (hyp. radians per sec.)
E	r. m. s. e. m. f. in a simple alternating-current circuit (volts or abvolts ∠)
$E = I Z'$	motional e. m. f. (r. m. s. abvolts ∠)
$\eta = r/r''$	mechanical efficiency of diaphragm, corresponding to armature efficiency in a synchronous motor (numeric)
η_0	mechanical efficiency of diaphragm, or friction and acoustic mechanical resistance to total mechanical resistance, at apparent resonance (numeric)
$\mathcal{F}_i$	m. m. f. due to constant exciting alternating current (r. m. s. gilberts ∠)
$\mathcal{F}_x$	m. m. f. due to vibratory displacement of diaphragm in permanent magnetic field (r. m. s. gilberts ∠)
$\mathcal{F}$	resultant vector m. m. f. in magnetic circuit (r. m. s. gilberts ∠)
$\mathcal{F}_0$	m. m. f. due to permanent magnet (gilberts)
f	impressed frequency (cycles per sec.)

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*The sign ∠ after a unit signifies that the quantity is a plane-vector or complex quantity as distinguished from a scalar or simple numerical quantity.

f_0,	impressed frequencies of apparent resonance (cycles per second)
f_r	reactive mechanical force of clamping(dynes $\angle$)
f_i	vibromotive force on diaphragm due to alternating current I alone (r. m. s. dynes $\angle$)
f_x	vibromotive force due to vibratory diaphragm displacement in permanent magnetic field (r. m. s. dynes $\angle$)
I	strength of constant small alternating testing current (r. m. s. absamperes)
$j = \sqrt{-1}$	
L	Self inductance of an electric circuit (abhenries or henries)
$\mathcal{L}$	Self inductance of a receiver winding with diaphragm damped (abhenries $\angle$)
m	Equivalent mass of a diaphragm (grams)
N	Number of turns in the winding of a bipolar receiver, including both coils (numeric)
N'	Equivalent number of turns for expressing a displacement m. m. f. in cm-turns (absamperes per cm. or gilberts per cm.).
P_e, P_e', P_e''	Electric power supplied to receiver with diaphragm damped, vector change in supplied electric power due to motion with diaphragm free, and total supplied electric power with diaphragm free. (abwatts or ergs per sec. $\angle$)
P_h	Increase in magnetic circuit power loss due to motion of diaphragm (abwatts $\angle$)
P_h'	Apparent increase in magnetic circuit power loss due to motion of diaphragm, as measured in the motional power circle diagram along the hysteretic axis before applying change in power scale abwatts $\angle$
P_i, P_i''	Damped magnetic power input (abwatts $\angle$), and input power from electric to magnetic circuit with diaphragm free (abwatts $\angle$)
P_m, P_m''	Mechanical output power of diaphragm against pure mechanical res. r (abwatts $\angle$) and total mechanical output power of diaphragm against total resistance of $r'' = r + r'$ (abwatts $\angle$)
P_{ma}, P_{ea}, P_{ha}	Active or dissipatory components of mechanical, electric, and hysteretic power (abwatts)

P_{mr}, P_{er}, P_{hr}	Reactive or non-dissipatory components of mechanical, electric and hysteretic power (j abwatts)
$P_r' = x^2 (r' + j s'/\omega)$	Motional power or power expended against reactive force of diaphragm displacement (abwatts ∠)
P_r''	Free magnetic power, or vector power of resultant m. m. f. $\mathfrak{F}$ on resultant magnetic flux ϕ, or total absorbed in magnetic circuit (abwatts ∠)
$p = N'/N$	Ratio of equivalent displacement turns to exciting turns (absamperes per cm.)
$\mathcal{P}$	Permeance of magnetic circuit (oersteds^{-1} ∠ or maxwells per gilbert ∠)
ϕ_i	Magnetic flux due to constant exciting current maxwells ∠)
ϕ_x	Magnetic flux due to displacement x in magnetic field (maxwells ∠)
$\phi = \phi_i + \phi_x$	Resultant magnetic flux (maxwells ∠)
R_1	Continuous-current resistance of receiver winding (absohms)
R	Apparent resistance of receiver to alternating current with diaphragm damped (absohms)
R_h	Increment of apparent resistance due to hysteresis and eddy currents, with diaphragm damped (absohms)
R'	Resistance component of motional impedance Z' (absohms)
R''	Total apparent resistance of receiver with diaphragm free (absohms)
R''_0	Total apparent resistance of receiver at apparent resonance (absohms)
r	Mechanical resistance of diaphragm including internal frictions and acoustic or air resistance (dynes per kine)
r'	Hysteretic resistance of magnetic circuit to motion of diaphragm, or apparent increase in friction of diaphragm due to displacement flux losses in magnetic circuit. (dynes per kine.)
$r'' = r + r'$	Total mechanical resistance to motion of diaphragm (dynes per kine)

R_0	Reluctance of magnetic circuit to permanent flux (oersteds)
S	Surface area of one pole neglecting magnetic fringe. (sq. cm.)
s	Effective stiffness coefficient of diaphragm to vibrational displacement (dynes per cm.)
s'	Apparent diminution in stiffness coefficient due to displacement in magnetic field. (dynes per cm.)
$s'' = s - s'$	Total effective stiffness of diaphragm including magnetic displacement (dynes per cm.)
t	Time elapsed from a certain epoch (seconds)
X	Reactance of a receiver winding with damped diaphragm (absohms $\angle$)
X'	Reactive component of motional impedance Z' (j absohms)
X''	Reactive component of receiver impedance Z'' with diaphragm free (j absohms)
x	Displacement of diaphragm towards poles from normal flexed position (r. m. s. cm. $\angle$)
x_0	Displacement of diaphragm at apparent resonance (r. m. s. cm. $\angle$)
$x_m = \lvert x_0 \rvert \sqrt{2}$	Maximum cyclic displacement of diaphragm at apparent resonance (max. cm.)
$\dot{x}$	Velocity of diaphragm r. m. s. kines $\angle$ or r. m. s. cm. per sec. $\angle$
$\dot{x}_0$	Velocity of diaphragm at apparent resonance (r. m. s. kines $\angle$)
$\ddot{x}$	Acceleration of diaphragm (r. m. s. kines per sec. $\angle$)
$y = 1/z$	Mechanical admittance of a diaphragm when the magnetic reactive force due to displacement is neglected (kines per dyne $\angle$)
y'	Apparent mechanical admittance of diaphragm, including magnetic reactive force due to displacement (kines per dyne $\angle$)
Z	Impedance of a receiver winding with diaphragm damped (absohms $\angle$)
$Z' = Z'' - Z$	Motional impedance of winding (absohms $\angle$)
Z''	Impedance of winding with diaphragm free (absohms $\angle$)

Z_0'	Motional impedance at apparent resonance, and at diametral or maximum size. (absohms $\angle$)
z	Mechanical impedance of a diaphragm with reactive magnetic force neglected (dynes per kine $\angle$)
z'	Effective mechanical impedance of diaphragm including reactive magnetic force (dynes per kine $\angle$)
$\omega = 2\,\pi f$	Impressed angular velocity (radians per sec.)
ω_0'	Impressed angular velocity at true mechanical resonance (radians-sec.)
ω_0	Impressed angular velocity at apparent mechanical resonance (radians per sec.)
ω_1, ω_2	Lesser and greater quadrantal angular velocities (radians per sec.)
r. m. s.	Contraction for root-mean-square.
$\lvert Z\rvert$	Size or mere numerical value of a vector quantity Z.

Bibliography

(1) Lord Rayleigh, "Theory of Sound", 1894, Vol. 1, pp. 366, 473.

(2) Wien, *Annalen, d. Phys.*, Vol. 4, 1901, p. 450.

(3) Henri Abraham, "Rendement Acoustique du Téléphone", *Comptes Rendus, Acad. d. Sc.*, 144, 1907.

(4) Henri Poincaré, "Étude du Récepteur Téléphonique", l'Éclairage Électrique, Vol. 50, Feb. 16, Feb. 23, Mar. 9, Mar. 16, 1907., pp. 221–372.

(5) A. E. Kennelly and Walter L. Upson, "The Humming Telephone". *Proc. Am. Phil. Soc.*, Vol. 47, pp. 329–365, July, 1908 .

(6) John B. Taylor, "Telegraph and Telephone Systems as Affected by Alternating-Current Lines", Trans. A. I. E. E., Oct., 1909, Vol. 28, Part II, p. 1169–1215.

(7) A. E. Kennelly, "Vector Power in Alternating-Current Circuits", Trans. A. I. E. E., Vol. 29, pp. 1233–1267, June, 1910.

(8) G. W. Pickard, "Telephone Receiver Efficiency". *Western Electrician*, May 6, 1911, Vol. 56, p. 899.

(9) A. E. Kennelly and G. W. Pierce, "The Impedance of Telephone Receivers as affected by the Motion of their Diaphragms", *Proc. Am. Ac. Arts and Sc.*, Vol. 48, Sept., 1912, pp. 113–151; also *The Electrical World*, N. Y., Sept. 14, 1912; also *British Assoc. Adv. Sc.* Report Dundee Meeting, 1912.

(10) Chas. F. Meyer and J. B. Whitehead, "The Vibrations of Telephone Diaphragms", Trans. A. I. E. E., Vol. 31, part II, 1912, pp. 1397–1418.

(11) Geo. D. Shepardson, "Equivalent Frequency of Telephone Currents", A thesis in the library of Harvard University, Cambridge, 1912.

(12) H. A. Affel and O. C. Hall, "Telephone Receiver Characteristics", Thesis, *El. Engg. Dept., Mass. Inst. Tech.*, June, 1914.

(13) Augustin Guyau, "Le Téléphone Instrument de Mesure", Paris, *Gauthier-Villars*, 1914.

(14) R. L. Jones, "Simple Vibratory Systems and their Impedance Analysis", Unpublished Memorandum, Engg. Dept., Western El. Co., 1914.

(15) L. Bouthillon and L. Drouet, "Étude Expérimentale du Récepteur, Téléphonique," *Comptes Rendus*, Vol. 158, June 2, 1914, p. 1568, also *La Révue Électrique*, Oct. 16, 1914, p. 294-295.

(15a) A. Guyan "The Telephone Receiver" *Journ de Physique*, June, 1914, Vol. 4, pp. 480–492.

(16) A. E. Kennelly and H. O. Taylor, "Explorations over Vibrating Surfaces of Telephonic Diaphragms Under Simple Impressed Tones", *Proc. Am. Phil. Soc.*, April, 1915, pp. 95–136, *Bulletin No. 7, Research Div. El. Engg. Dept., Mass. Inst. Tech.*

(17) A. E. Kennelly and H. A. Affel, "The Mechanics of Telephone-Receiver Diaphragms, as Derived from their Motional Impedance Circles", *Proc. Am. Ac. Arts & Sc.*, Nov., 1915, Vol. 51, pp. 422–482, *Bulletin No. 8, Research Div., El. Engg. Dept., M. I. T.*

(17a) B. S. Cohen and J. G. Hill "Long-Distance and Cable Telephony", *Inst. P. O. Elec. Engrs.* 1916.

(17b) "Notes on the Electromagnetic Theory of the Telephone" by R. L. Wegel, an unpublished memorandum of the Western Electric Co.

(18) A. E. Kennelly and H. O. Taylor, "Some Properties of Vibrating Telephone Diaphragms", *Proc. Am. Phil. Soc.*, April, 1916, Vol. 55, pp. 415–460, *Bulletin No. 11, Research Div., El. Engg. Dept., M. I. T.*

(18a) M. Latour "Theory of Telephone Receiver" *La Lum. Elec.* Vol. 33, June 17th and July 22, 1916.

(19) Geo. D. Shepardson, "Telephone Apparatus", Appleton & Co., 1917.

(19a) B. S. Cohen "Telephonometry" *The Electrician*, Vol. 77, May 26th and June 2nd, 1916, pp., 244–245 and 277–279.

(20) H. O. Taylor, "Motional Impedance Circle of the Telephone Receiver", *Proc. Radio Club of America*, June, 1917.

(21) Henri Tournayre, "Théorie du Téléphone" *L'Industrie Électrique*, July 25, Aug. 10, 1917.

(22) A. E. Kennelly, "Some Experiments on the Effects of Changes in Diaphragm Thickness on the Characteristics of a Telephone Receiver", *Journal of the Franklin Institute*, November, 1917, Vol. 184, pp. 723–726.

(23) John Mills, "Radio Communication", McGraw-Hill Book Co., 1917, pp. 26-35.

(24) W. H. Eccles, "Wireless Telegraphy and Telephony", D. Van Nostrand Co., 1918, pp. 347–350.

(25) Marius Latour, Note sur les Pertes dans les Tôles de Fer aux fréquences élevées. *Révue Gén. de l'Él.* Vol. 3, April 13, 1918, pp. 539–543.

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SOME POSSIBILITIES OF STEAM RAILROAD ELECTRIFICATION AS AFFECTING FUTURE POLICIES

BY CALVERT TOWNLEY

ABSTRACT OF PAPER

Electricity fills every requirement of railroad service, but as it involves a large investment, electrification has proceeded slowly. Electrification has also been retarded because the problem has been largely considered one of replacing the steam locomotive by the electric locomotive whereas in reality the problem is much broader. It really offers a fundamentally different method of train propulsion because the limitations of the steam locomotive disappear and the strictly limited motive power is replaced by one that is practically unlimited, thereby opening up many possibilities in the methods of railroad operation. While there are a number of different systems of electric traction all of the systems have many features in common and the possibility of unlimited electric power is a characteristic of them all. A brief review is given of electrified sections of railways showing the advantages which have been realized in both the freight and passenger service. Existing electrifications have been operated for a sufficient length of time so that operating statistics are now available, and any proposed undertaking may therefore be predicated on established facts. While electrification will greatly increase track capacity, there is a large railroad mileage which already has more than sufficient capacity, in which case electrification would not be justified. On the other hand, there are so many cases where its advantages are clear and conclusive that when the railroads are able to finance their required electrification it will test the capacity of the electric factories of the country to serve them.

ELECTRICITY now performs every railroad service previously rendered exclusively by steam locomotives and in every case does it better than it was done before. But in order to use electricity a large investment in equipment and installation must be made and electrification has proceeded slowly because railroad executives were not convinced that the advantages to be gained are always worth the cost.

The progress of electrification has also been impeded, first, before the war by the difficulty in financing, due to conditions other than the merits of electrification, and second, since the war began, because every one has been too busy to consider any work that could be deferred and because the government's taking over the railroads has created an unsettled situation not conducive to the investment of new capital for future returns. Now, however, there seems to be ground for hoping that these bars to progress will be removed in the not distant future so that electrification can be again studied on its merits, therefore our consideration of the subject is timely.

In reviewing the past twenty years history of this question, I cannot escape the conclusion that we electrical men, and not our steam road colleagues are responsible for the slow progress made. We have not known enough about either the science or the art of railroading. Our belief in, and our zeal for our own profession has lead us, albeit with entire honesty of purpose, to make more or less extravagant claims as to what we could do and to underestimate the cost of doing it. The inevitable reaction of mind which followed an accurate determination of facts of course disturbed confidence in our judgment. But if at times we have injured the cause of electrification by claiming too much, strange as it may sound, we have injured it a great deal more by not claiming enough. Electrical engineers not having always been railroad men, have been unable to study railroad problems as they should have been studied, that is to say with only real and not with any arbitrary limitations before them. It has been natural for the electrical man to ask the railroad man for a statement of the conditions he was expected to meet. It was equally natural for the railroad man to prescribe the conditions upon which his steam service was predicated. Under these circumstances the problem became largely one of replacing one sort of locomotive with another, and of balancing hoped-for economies in operation and maintenance on the one hand, against fixed charges for the additional investment required, on the other. Right there comes the mistake. A perfectly natural but yet a fundamental mistake, for which no individual or class should be censured but for which the unusual development of the art is responsible. We cannot blame railroad men for not being electrical engineers nor electrical engineers because they are not railroad men but the progress of electrification has had to lag until both should be able to see, each with the eyes of both. It is only by combining the railroad's man knowledge of the fundamental requirements of his service with the electrical man's skill in applying electricity to perform that service that all the possibilities of any specific problem may be developed.

The electrification of a railroad is not simply the substitution of one kind of locomotive for another. It is far more than that. It is the adoption of a fundamentally different method of train propulsion. It is conservative to say that, within the bounds of ordinary practise, electricity can furnish every train with all the pulling power that can be used. The limitations of the steam locomotive in this respect disappear and ruling grades rule no longer. A strictly limited motive power is replaced by one that is practically unlimited.

There are a number of so-called "systems" of electric traction and heavy emphasis has been laid by the advocates of each upon its points of difference from every other. So much has been said about these differences and so little about the points of similarity as to create an entirely misleading impression. It is a fact that there are more kinds and types of steam locomotives in use many times over than there are electric systems. It is a fact that except for the storage battery locomotive, which has but a limited field of application, all electric systems have many more common features than differences. It is a fact that they agree on fundamentals and differ in detail only. Their costs may not be the same, their efficiencies may vary but they all do their work and do it successfully and well. The possibility of unlimited electric power is a characteristic not of any one system but of all. It is due to basic differences between steam and electric equipment. A steam locomotive is a complete independent unit which not only generates but also utilizes its power. The electric locomotive generates no power at all. It is only a translating device receiving energy from an outside and a remote source. The electric power house always having much greater capacity than any one locomotive, can supply ample power for the heaviest train on the steepest grade. The steam locomotive which carries its own power house with it is limited to the capacity of its one boiler. By the multiple unit principle, as many electric locomotives as may be needed can be coupled together and operated in synchronism by one crew from any cab. Any required tractive effort can thus be exerted without slipping the wheels, without imposing undue strains on the rails or bridges and without increasing the number of engine crews.

The business of a railroad is to transport freight and passengers. I put freight first because on the average it produces 73 per cent of the revenue. Unlimited motive power permits longer trains and higher schedule speeds. On the Elkhorn grade of the Norfolk & Western the schedule speed was doubled. It cuts the operating cost by hauling more cars with the same or a smaller crew. The Norfolk & Western uses two electrics to do the work of three Mallets. These new opportunities at one fell swoop banish many of the railroad's time honored traditions. The traffic possibilities must be studied from a new angle and advantage taken of every facility. It is a new thought to realize that train length is limited not by motive power but by the yard tracks and length of sidings, or that all the trailing tonnage that the draw bars will stand can be hauled. Nor are these new limits fundamental. Sidings can be extended, draw bars can be made stronger, if it pays to do it. In a word electrification opens up tremendous possibilities of increasing the freight capacity of a road and without it being necessary to build additional tracks.

While not as important as freight, passenger traffic likewise comes in for its share in the widened horizon and the vanishing tradition. Unlimited power of course is available but the absence of combustion is another basic advantage. Smoke and cinders disappear. Tunnel operation loses its terrors. Unobscured signals permit normal speeds with undiminished safety. Projects like the Pennsylvania terminal in New York depending entirely on submarine tunnel operation and previously impracticable, become immediately possible. Railroads owning valuable realty in cities can erect buildings thereon, where before smoky locomotives made any structure above the ground level impracticable. The aerial rights are now valuable. Multiple unit operation has in fact made suburban traffic. The rapid acceleration made possible by electric traction has directed attention to the equal value of rapid retardation and has quickened the study of braking accordingly; also of modified coach design to bring about the more efficient loading and discharge of passengers. These combined possibilities secure increased schedule speeds and attract patronage. The people not only get over the line in a shorter time but as a corollary more people get over it in the same time. Again it is seen therefore that in passenger as in freight traffic the ability to do something that could not be done before, rather than to do the same thing at a lower cost is the most valuable attribute of electrification, and again we find a greatly augmented capacity without the need of additional tracks.

It is not my purpose to make an exhaustive comparison of the relative advantages of steam and electric operation. That has been done often and well by others. What I have said about the expanding opportunities for electrified service is by way of illustration to emphasize my plea that the question should always be viewed in its broader aspect and not hampered and restricted within any narrower limitations than properly belong to it.

I am going to assume, then, the broadest possible treatment and to suppose that every electrification project is to have its pros and cons most fully examined. The real and vital question then is, "How far will this lead us?" "To what extent may we expect complete electrification of all our roads?" Parts of a number of them have already been equipped. Many of these are numbered among our prominent roads, successful corporations which have had the advice of the most highly skilled executives and engineers, and which are progressive. The service performed on the electrified sections comprises practically every kind of railroad transportation. The Bluefield division of the Norfolk & Western R. R. in West Virginia is an example of an important coal road operating through the mountains. The Chicago, Milwaukee & St. Paul 440-mile main line, through Idaho and Montana, demonstrates what can be done by a transcontinental carrier on a large scale with through traffic, both freight and passenger. The New York, New Haven & Hartford R. R. 73-mile stretch between New York and New Haven shows how through freight and a heavy passenger traffic can be taken care of on the most congested four track section of an important eastern carrier and what is possible for complicated freight yard operation, while the New York Central and the Pennsylvania out of New York City are splendid examples of our greatest modern passenger terminal electrifications. There are of course many other electrifications, but even if there were not, those named are of a character to command the respect and attention of the railroad world. Now, every one of these projects has been successful. Every one has justified itself. Nearly every one in its present scope represents an extension of the zone initially electrified, the most convincing evidence possible as to what views the operating companies hold regarding these several projects. Railroad officials are generally glad to give others the benefit of their experience so it is reasonably safe to say that operating statistics are available covering long enough periods so that the results to be expected from any proposed undertakings may be predicated on established facts and not upon theories. In the light of present day knowledge, therefore, what answer can we make to the question "Should all railroads be electrified?"

Taken together in 1910 there were in the United States 240,000 miles of railroad main line regardless of the number of tracks. Of this mileage approximately 1250 or one half of one per cent has been electrified or is today in process. The remaining 99½ per cent comprises of course, roads performing every variety of service. They range from the back country branch line built by some over enthusiastic promotor and now perhaps, operated as part of a large system, only because operation cannot be avoided and regularly contributing its annual deficit, up to the most important through arteries of travel upon which the commerce and industry of the nation depend. Every sort of community is served; every kind of railroading has its place in this vast aggregation of effort and the variables in the problem are so multitudeness and their nature often so profound as to well daunt the courage of one who seeks to formulate them for incorporation in a general statement. Fortunately or unfortunately, depending on the point of view, it has been my lot to have to deal with this electrification problem from both sides. At one period from the standpoint of an intimate affiliation with the development and manufacture of electrical apparatus and at another from that of one charged with official responsibility on the railroad's behalf. I am a thorough believer in the virtues of electrification and an enthusiast about the wonders which it can accomplish but I also have a keen appreciation of the almost infinite variations in the railroad problem and a very wholesome respect for the dollar. I do not believe that all railroads will ever be electrified. I am not sanguine even that all the tracks of any one really big system will be so equipped in our time. It is a question of economics, and the results will not justify the expenditures even when considered with such broad vision as that which guided the Pennsylvania in spending millions to put their passenger terminal in New York City without the prospect of a direct return. Electrification will increase the track capacity. But there are thousands of miles of railroad that have sufficient capacity now, frequently several times over, and where the wildest stretch of imagination fails to picture a future need of this kind. Electrification works wonders in suburban and interurban passenger service. I have ridden for hours across the western prairies without seeing a single town, much less a city where these advantages would count. Electrification effects marked economies in fuel, in maintenance, in labor and otherwise through a long list; but electrification calls for a heavy investment and unless these economies bulk large enough, the interest on such investment will wipe them out and turn the enterprise into a losing venture. I do not believe the cause of electrification is helped by undue optimism on the part of its advocates. Rather should there be an enlightened partisanship, enthusiastic where enthusiasm is justified but tinged with the sober conservatism of the man who has to put his own dollars to work.

There need be no discouragement to the electrical engineer in the views just given, nor to the railroad man who has looked toward the new motive power for salvation. There are so many cases where electricity should be used, where its advantages are clear and conclusive, that once the railroads escape from the financial slough of despond in which they are now wallowing and are again able to get capital for their needs, there will not be enough engineers, there will not be enough electric factories in the country to serve them. Every big system has need of electricity somewhere. For some small roads it may mean the difference between solvency and bankruptcy. I electrified a short derelict line for the New Haven Road between Meriden and Middletown, long before given over into the one-train-a-day-annual-deficit class, and turned it into a good earner.

There can be no rule established. Generalities are sure to be misleading but electrification is now firmly intrenched and successful. It is recognized by railroads generally as an effective agency with great possibilities and one which is particularly valuable for certain specific purposes. Time alone will tell how broad its application is to be but I am confident we can await developments with tranquility assured that the art is in a healthy condition and that progress will be along the right lines.

An address presented at the 7th Midwinter Convention of the American Institute of Electrical Engineers, New York, February 20, 1919.

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ENGINEERING AND INDUSTRIAL STANDARDIZATION

BY C. A. ADAMS

INTRODUCTION

MOST of us speak of standardization in a vague sort of way, usually having in mind some particular corner of the field, but without sensing the comprehensiveness of the word or the magnitude and importance of the field covered, not realizing that the cooperation without which our modern society would be impossible, would in turn be impossible without a large measure of standardization. It might almost be said that the degree of standardization in any nation is a measure of its civilization, certainly in the material or industrial sense of the word.

Even in the tribe a common language was necessary, namely a standardization of the meaning of words. A dictionary is merely a recorded standardization of the spelling, pronunciation and meaning of words, as determined by usage and common consent. To be sure we still have dialects and colloquialism, but these are gradually decreasing. In civilized intercourse the accurate use of words is absolutely essential to mutual understanding, however rare it may be, and although new words are being slowly added, the meaning of each must be stable, that is standardized, if it is to serve its purpose.

As between nations we still have many different languages, although most of the civilized world now uses substantially the same alphabet and there is a persistent effort to establish a universal language.

After language, followed standardization in coinage, weights and measures. Our present Bureau of Standards is the outgrowth of the old Bureau of Weights and Measures, which was largely the repository for standards of length, weight, volume, etc. Imagine the hopeless confusion in this country if each state had its own language as well as its own system of coinage and of weights and measures. Even as between nations differences in language, coinage, weights and measures, constitute serious barriers to intercourse, social and commercial, which tend to prevent interchange of ideas and commodities and thus to retard that mutual understanding which makes for peace.

But standardization has already extended far beyond these fundamental fields and is now growing with leaps and bounds.

It is my purpose in presenting this subject to discuss chiefly standardization in these less fundamental fields; to point out its importance and its dangers; to indicate the comparative chaos which still reigns in most parts of the field of engineering and industrial standardization, not only in the standards themselves but underlying this in the methods of creating them; and finally to outline the machinery proposed by the American Engineering Standards Committee to remedy this condition.

Before undertaking the general discussion a brief classification and review of each field may be of interest, excluding the alphabet and coinage as outside of the engineering and industrial group.

CLASSIFICATION OF STANDARDS

Language. Definitions of scientific and technical words, terms, phrases, abbreviations, symbols and diagrams.

Standardization of these elements of our technical language is just as fundamental to intelligent intercourse in this field as in the case of ordinary word intercourse; in fact it is more fundamental since we are here dealing mostly with accurately measurable quantities.

Some progress has been made in this field even to the extent of international standardization of terminology, but chiefly in connection with very fundamental matters, there being still in the outlying fields a very wide diversity of usage in the matter of symbols, abbreviations and diagrams, and in a lesser degree in the use of words. There are at least fourteen different organizations in this country alone, each of which has its own system of diagrammatic representation covering electrical wiring and devices. Many other similar illustrations are available of the frightful inefficiency of the present haphazard uncoordinated work in this field.

Standards of Quantity. Length, area, volume, mass, weight density, pressure, heat, light, illumination, electricity, magnetism, radioactivity, physical constants and their relation to each other.

Some of the fundamental standards of this group are of such importance in the every-day life and trade of a nation that they are prescribed by law and each city or county has the necessary machinery for enforcing the law.

Nearly all European nations as well as the Latin-American nations have adopted the rational metric system, whereas the English speaking nations still cling to the English system with its confusion of oddly related weights and measures.

However since the electrical and magnetic units are the same the world over, since they are based upon the metric system, and since practically all scientific work is handled by that system, a vast amount of time is wasted by the English speaking nations not only by the necessity of becoming familiar with both systems, but also in their use due to the frequent necessity of transformations from one to the other. This latter loss is particularly serious in the field of electrical engineering. It is my own conviction that in the case of a real electrical engineer, a full year of his professional life is wasted on this account. This is partly during his educational work and involves an immense loss of efficiency due to the diversion of his attention from the real understanding of the subject.

Standards of Quality. Specifications for materials together with standard methods for testing their qualities.

Certain standards of this type are also of such importance to the welfare of society that they are prescribed by law notably in the food field, and a bill is now before Congress for the standardization of fertilizers.

Standard specifications and tests for the materials of engineering and construction are almost wholly prepared by the American Society for Testing Materials, which society was organized solely for this purpose. In no other field is the work of standardization better organized.

Standards of Performance. Operating characteristics of machines and devices, output, rating, speed, efficiency, durability, etc., as specified in terms susceptible to measurement, together with the methods of making these measurements.

The most notable example of comprehensive work in this field is to be found in the Standardization Rules of this Institute. Another is in the Power Test Code of the A. S. M. E.

Standards of Practise. Regulations or codes dealing with construction, installation and operation, based upon considerations of safety, quality, economy, convenience, etc.

The oldest code in the electrical field is the National Electric Code of the N. F. P. A. first issued in 1897 and since frequently revised. This has been largely copied in the local municipal regulations of most large cities.

The National Electrical Safety Code was issued about three year ago by the Bureau of Standards after long and careful collaboration with the most interested organizations. This covers safety to life rather than to fire.

The Boiler Code covering standards of construction for boilers was issued by the A. S. M. E. in 1914 after some years of laborious work involving cooperation with the interested organizations.

There is now under consideration the preparation of some fifty odd industrial safety codes. This work will probably be carried out according to the procedure prescribed by the American Engineering Standards Committee, outlined below, with the appropriate organizations acting as sponsors. The Bureau of Standards will doubtless serve as sponsor for some of these codes.

Dimensional and Type Standards. In any product the standardization of types, sizes or sets of dimensions in order to reduce the number of types and sizes and hence the cost of production.

A few illustrations will indicate the tremendous scope of this group and the comparative chaos that still reigns.

Among the earliest and most fundamental attempts in this group are:

Screw Threads, Bolts, Nuts, etc.

In 1864 a Committee of the Franklin Institute recommended the adoption of a system devised by William Sellers, now known as U. S. Standard.

In 1884 Charles Bower, of Warder, Bushnell & Glessner, Springfield, Ohio, adopted standard sizes of screw threads for bolts and taps, based upon the U. S. Standard screw thread.

In 1895 the American, Hartford and Worcester Machine Companies issued standards for set-screws and cap-screws, also based upon the U. S. Standard screw thread.

In 1906 the Association of Licensed Automobile Manufacturers adopted standards for automobile screws and nuts.

In 1907 the American Society of Mechanical Engineers accepted the report of its committee on standard proportions for machine screws. This Committee was appointed in 1902, and had devoted five years to the task. As far as the screw threads themselves are concerned, the American Society of Mechanical Engineers standard differs only in very minor details from the Sellers' or U. S. Standard, but the A. S. M. E. report gives standards also for taps, special screws, special taps, and screw heads of various types, together with tolerances.

In 1912, the Society of Automobile Engineers was organized and has adopted fine screw thread standards, as well as many other size standards of automobile materials and parts.

In the fall of 1918 a screw thread commission was appointed by act of congress and is still at work. In this work some consideration is being had of the international situation, and although there are obviously great difficulties in adapting our threads to those of the metric system nations, the differences between the U. S. and the British threads are slight, though sufficient to prevent interchangeability without excessive tolerances.

I have been told on good authority that there are fifteen different types of screw thread standards in use by the War Department alone.

Wire, Drill and Sheet Metal Gages

Of these there are several varieties still in use, although for copper wires, the Brown & Sharpe or American Wire gage is most commonly used for the smaller sizes, and the Edison or circular mil gage for all sizes above 0000 B. & S. All these gages were originally adopted by some corporation such as the twist drill gage of the Morse Twist Drill & Machine Company, the Stubbs steel wire gage, etc.

An act of Congress in 1893, established the Standard Gage for sheet iron and steel. Previous to this time there were many gages in use, and the addition of this one seemed only to add to the confusion.

In 1895 a joint Committee of the A. S. M. E. and the American Railway Master Mechanics Association agreed to recommend the use of the decimal gage,—that is a gage whose number is the thickness in thousandths of an inch, and to recommend the abandonment and disuse of the various other gages then in use.

In 1904 the Westinghouse Electric and Manufacturing Company abandoned the use of gage numbers referring to wire, sheet metal, etc.

There are now at least eight different sheet metal gages in use in this country.

Other fundamental standards in this group are,—pipe threads and flanges; pipe unions; and special threads for fixtures and fittings, *e. g.* incandescent lamp sockets. Consider the enormous saving in expense and the convenience resulting from our almost universal standard lamp socket.

In the less fundamental part of this field, namely the standardization of types and designs, most of the work has been done until comparatively recently, within individual corporations as a matter of production economy. A notable example of this is the Ford automobile.

But within the past few years much has been accomplished in the automobile industry as a whole by the S. A. E.

This also is true in certain parts of the railway field in the standard freight and passenger cars, through the Master Car Builders Association. The variety is however still enormous.

There are at least 500 different types of locomotives, although the U. S. Railroad Administration has recently reduced the standard types of passenger locomotives to twelve.

One of the most striking examples of the possibilities in this field is the attempt only just started by one of our most progressive manufacturers of electrical machinery, a member of this Institute, to develop standard electric motor designs. Nine manufacturers are working together to this end. Consider the immense advantage to the consumer resulting from the general interchangeability of parts, and the reduction in the number of spare parts carried by a user who has motors of several of these cooperating manufacturers. Moreover the designs will contain the best features of all these makes, and there will still remain ample opportunity for competition in production cost, and quality of workmanship.

NEED AND VALUE OF STANDARDIZATION

This would hardly seem to need argument, but a few illustrations may not be out of place.

Not many years ago the average automobile had nearly as many sizes and types of bolts as there were bolts on the car, with a resulting inconvenience almost insufferable. Since that time the Society of Automobile (now Automotive) Engineers has carried on a tremendous campaign of standardization which has not only vastly reduced the annoyance of repair work to the purchaser but has greatly reduced the cost of automobiles. It is also largely responsible for the unquestioned primacy of this country in that field.

Another illustration from the same field was when that same Society started to standardize the sizes of steel tubing. All the manufacturers agreed except one who persisted in his odd sizes. Shortly thereafter this manufacturer, wishing to purchase some steel tubing, asked for prices and shipment. He was told that the price would be about 30 per cent higher than for the standard sizes, and that the shipment would be made in three months as against immediate shipment of the standard sizes from stock. It is needless to say that this manufacturer soon adopted the standard sizes.

An illustration from the electrical field has to do with the rating of electrical machinery. In the early days there was no agreement as to what was meant, *e. g.*, by a ten horse power motor. As a result fair competition was impossible. The ratings of the several manufacturers varied as much as 30 per cent and the customer was at the mercy of the pursuasive talents of the salesman. It took the Standards Committee of the A. I. E. E. five years to revise its old system of rating of electrical machinery in such a way as to be rational, scientific, satisfactory to all concerned, and capable of reasonably accurate checking by commercial tests. The results of this work have proved to be of world-wide value. They have placed competition on a far more equitable and generally satisfactory basis; they have encouraged more careful and thorough designing; they have encouraged a more careful selection of size on the part of the user, and have generally resulted in better machines.

DANGERS OF STANDARDIZATION

In certain fields notably in standardization of types and in dimensional standardization when the latter is carried into complete designs, there is an obvious danger that standardization may develop into crystallization and serve as a brake on progress; but this is merely an obstacle and not an argument, since it is obviously possible to keep the standards abreast of progress. There is certainly no more difficulty in improving

12 standard types of locomotives than in making the same improvements in the 500 types which exist today. If the twelve types are not sufficient to meet effectively the variety of demands of service, make it 20 or 30 or 50; but the maximum real need will certainly be so far below the present number as to constitute an annual saving of many millions.

The more fundamental a field the greater the need of standardization, and the greater the difficulty of making a change.

A notable example of this latter difficulty is in connection with our abominable English system of weights and measures which just "happened" in those early days when the importance of a rational or simply related system was not appreciated. Now each generation is unwilling to shoulder the expense of a change which will be of chief benefit to ensuing generations. But this would hardly constitute a sufficient reason for never adopting a standard system of weights and measures.

Similarly but in quite a different field, it could hardly be claimed by the most pessimistic that standardization in the manufacture of automobiles had been anything but a striking success.

MACHINERY OF STANDARDIZATION

At present the work of standardization is carried on by numerous organizations each in its own field and with its own machinery, usually through a standards committee. But the fields overlap and the machinery differs largely in the different organizations. In many cases the committees are made up of men who do not realize that a standard must be not only rational and technically correct but also acceptable to all those interested in its production and use. The mere promulgation of a standard by any society however powerful, does not make it a real standard.

Moreover the fields of the several organizations overlap in large degree; there is much duplication of effort and confusion of result, and many of the standards promulgated are practically useless.

Cooperation between two or more organizations has been tried, sometimes successfully, but there was no recognized machinery of cooperation, no standard procedure, and confusion still reigns.

To meet this need there has been recently created an American Engineering Standards Committee whose purpose, organization and method of operation are outlined below.

AMERICAN ENGINEERING STANDARDS COMMITTEE*

The American Engineering Standards Committee was formed by joint action of five national engineering societies (American Society of Civil Engineers, American Institute of Mining Engineers, American Society of Mechanical Engineers, American Institute of Electrical Engineers and the American Society for Testing Materials), called the *Founder Societies,* to meet a long felt need of some available and satisfactory machinery for the development of engineering and industrial standards, by the operation of which duplication would be avoided and cooperation between all interested organization and Government departments secured; so that when a standard or group of standards is developed it will be acceptable to all concerned and therefore a real American standard. Moreover as international standardization develops, there is imperative need for an authoritative national body to deal with the corresponding foreign bodies. National Engineering Standards Committees are already in operation in England, Canada, France and Holland, and others will undoubtedly be organized in the near future.

The A. E. S. Committee machinery now proposed for the development of standards is made up as follows:

a. The Committee proper or the *"Main Committee"* (with three representatives from each of the five "Founder Societies" and of three Government departments), whose functions are chiefly those of an organizing, coordinating and steering Committee.

The War Department, the Navy Department and the Department of Commerce (Bureau of Standards) have already been invited to join in this movement and to appoint representatives on the Main Committee. The War Department has already accepted the invitation and is now appointing representatives. Assurances are at hand that the other departments will also accept.

b. *Sectional Committees* one for each group of standards (with representatives from all organizations or Government departments vitally interested in that particular group of standards) whose function is to prepare the standards in question under the direction of the most vitally interested organization known as the "Sponsor Body".

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*In discussions with prospective cooperating societies, certain proposals for changes in the method of selecting the members of the Main Committee have been proposed and are under consideration; but these changes will not affect the general procedure or interrupt the continuity of the work of the Committee.

c. The *Sponsor Society* or *body* may be one of the Founder Societies, a Government department, or one of the "Cooperating Societies" or organizations.

d. Under *Cooperating Societies* it is intended to include all organizations interested in the production of standards and willing to cooperate.

PROCEDURE

1. When the development of a particular group of standards is proposed, the Main Committee assigns the work to the appropriate organization as "Sponsor", or, if the situation seems to indicate that more than one organization is equally interested, to these organizations as "Joint Sponsor."

2. The sponsor then appoints the Sectional Committee subject to the approval of the main committee. The purpose of this approval is merely to assure the comprehensive representation of all the interests involved. Complete records of all interested organizations and of their standardization work will be kept on file and properly classified in the office of the Main Committee. The Main Committee or its Secretary will thus be able, either promptly to suggest the proper representation to a sponsor on request, or to approve or amplify the representation as provisionally proposed by the Sponsor.

3. After a group of standards has been prepared and accepted by a Sectional Committee, it is submitted to the Sponsor Body for its approval and then to the Main Committee with a full report of its history. When approved by both the Sponsor Body and the Main Committee, the standards in question become American Standards.

4. When the report of any sectional committee is being considered by the Main Committee, three members of that sectional committee are invited to sit with the Main Committee to report, discuss and vote on the standards in question as if they were regular members of the Committee. Thus each sectional committee, (and therefore usually each Sponsor Body), will be represented on the Main Committee when standards in which they are interested are being discussed.

5. The scrutiny of a standard by the Main Committee is to make sure that the proper procedure was pursued, that it was prepared by a comprehensively representative sectional

committee, that the vote of acceptance was nearly enough unanimous, and that the standard is consistent with other related standards. Consideration is also given to international relations; but the Main Committee is not supposed to pass upon the details as it is obviously impossible for a moderate sized workable committee to cover the details of all parts of the field.

6. After approval by the Main Committee the standard is published by the Sponsor Body with the statement that it has been approved by the A. E. S. Committee, and labelled "American Standard" with the appropriate descriptive title.

Briefly summarized this procedure is as follows:

Standard assigned by Main Committee to Sponsor Body.

Sponsor Body appoints a thoroughly representative Sectional Committee, subject to approval of Main Committee.

Sectional Committee prepares standard and submits to Sponsor Body which then submits the standard with its approval to the Main Committee.

The Standard is then published by the Sponsor Body and labelled "American Standard."

The machinery thus provides for absolutely comprehensive cooperation, eliminates overlapping and duplication of effort, and yet does not undesirably restrict the initiative of the several cooperating societies.

With proper support and the cooperation of all interested organizations, it should contribute largely to the industrial development of the country.

Moreover it should be a potent factor in promoting international standardization and foreign commerce.

In the broad sense international standardization means a common industrial language and the removal of one of those barriers which tend to separate nations and to give rise to misunderstandings.

The more of these barriers we can remove, the more likely we are to attain that lasting peace which the world longs for.

Presented at the Seventh Midwinter Convention of the American Institute of Electrical Engineers, at a Joint Session with the American Institute of Mining Engineers, New York, February 20, 1919.

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(*Subject to final revision for the Transactions.*)

WELDING MILD STEEL

BY H. M. HOBART

Abstract of Paper

The probability that welding could, with advantage, be more widely used in ship construction than had heretofore been the case, led to the formation, in 1917, of a Welding Committee, which at first was conducted under the auspices of the Standards Committee of the Institute. The Welding Research Sub-Committee, formed in 1918, was a sub-committee of the Metallurgical and Electrical Sections of the Engineering Division of the National Research Council, and the Welding Committee, (under the chairmanship of Professor C. A. Adams) came under the direction of the Emergency Fleet Corporation. The paper is in large part based on the work done by the Welding Research Sub-Committee up to January of this year.

THIS paper deals principally with investigations undertaken by the Welding Research Sub-committee of the Welding Committee of the Emergency Fleet Corporation. The general object of the investigations has been to extend the use of welding in the construction of merchant ships and, specifically, to provide a definite basis for obtaining the best economy and efficiency in employing welding in place of riveting in the construction of the hulls of such ships.

Composition of Ship-Plate Steel. The chemical composition of the steel employed in such hull construction varies with the thickness of the plates. Through the courtesy of Mr. H. Jasper Cox, of Lloyd's Register of Shipping, the following information may be given concerning the kind of steel plate employed in American Shipyards in 1918 for the hull construction of merchant ships.

Lloyd's requirements do not relate to the chemical composition. They require a tensile strength of 58,000 lb. per square inch (40.75 kg. per sq. mm.) for their lower limit and 72,000 lb. per square inch (50.59 kg. per sq. mm.) for their upper limit. For the information of the Committee, Lloyd's obtained from their surveyors at various works data of the carbon content, which are as follows:

Works		Carbon Content for Plates ¼ in. thick	Carbon Content for Plates 1 in. thick
A		0.14	0.23
B		0.14	0.25
C		0.19	0.25
D		0.20	0.30
E	Upper Limit	0.30	0.35
	Lower Limit	0.24	0.29
F	Upper Limit	0.25	0.30
	Lower Limit	0.21	0.27
G	Upper Limit	0.25	0.35
	Lower Limit	0.22	0.28

For shapes, Works H employ:

Shapes about ½ in. thick, 0.24 per cent to 0.30 per cent carbon.

Shapes about 1 in. thick, 0.28 per cent to 0.35 per cent carbon.

Small shapes such as:

2½×2¼× ¼-in. angles, about 0.15 per cent carbon.

4×4× ⅞-in. angles, about 0.20 per cent carbon.

From several tons of half-inch thick (12.7 mm.) plate from the yard of the Chester Shipbuilding Company, which was employed in making many sample welds in an investigation designated the Wirt-Jones Tests, seven analyses were made at the Bureau of Standards. The maximum and minimum percentages of each of the impurities for these seven samples were as follows:

	Maximum per cent.	Minimum per cent.
Carbon	0.25	0.24
Manganese	0.46	0.45
Phosphorus	0.043	0.039
Sulphur	0.031	0.027
Silicon	0.052	0.024

For this material the Bureau of Standards reports:

Yield point, 37,900 lb. per sq. in.

Ultimate tensile strength, 63,600 lb. per sq. in.

Elongation in 2 in., 38.6 per cent.

The following manufacturer's data apply to about ten tons of half-inch ship plate supplied by the Worth Steel Company, of Claymont, Del., and to be used for testing electrodes:

Chemical Analysis (Ladle Analysis)	
Carbon	0.29 per cent.
Manganese	0.37 per cent.
Phosphorus	0.015 per cent.
Sulphur	0.032 per cent.
Physical Properties	
Tensile strength—lb.per sq. inch	67,400
Elongation, per cent in 8 inches	25.25 per cent.

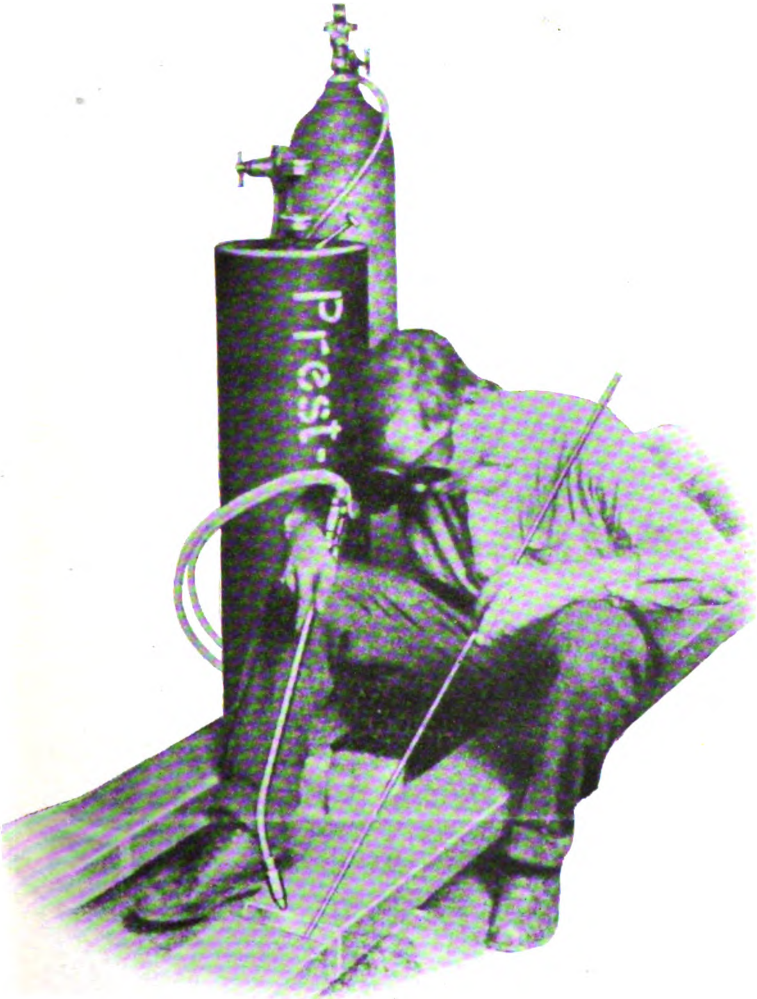

FIG. 1—GAS WELDING [HOBART]

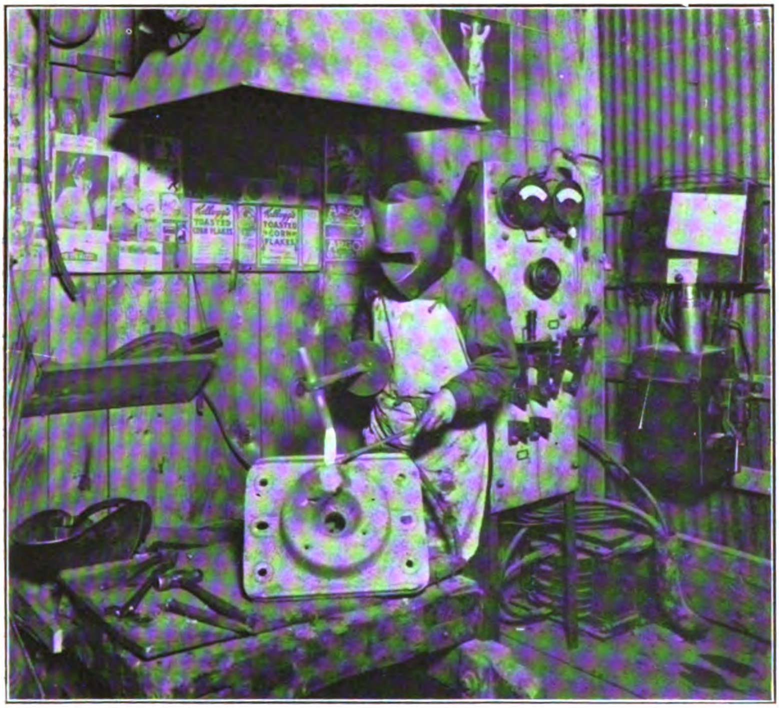

FIG. 2—CARBON-ARC WELDING

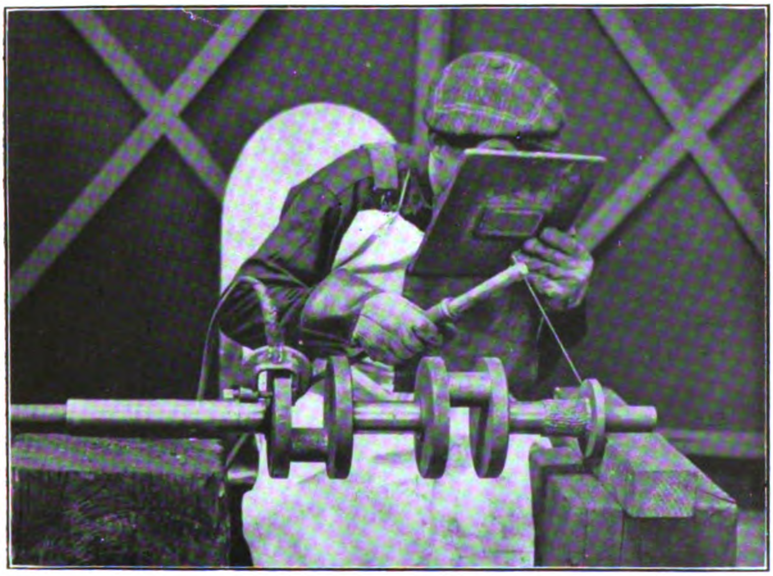

FIG. 3—METAL-ARC WELDING

[HOBART]

Another lot of about 1½ tons of ½-in. and 1-in. ship plate from another source was analyzed by the Electrical Testing Laboratories with the following result, four analyses being made for each thickness:

	Maximum per cent		Minimum per cent	
	½ in.	1 in.	½ in.	1 in.
Carbon	0.24	0.28	0.22	0.26
Manganese	0.44	0.53	0.40	0.47
Phosphorus	0.033	0.033	0.028	0.027

The specifications of the American Society for Testing Materials for structural steel for ships (serial designation A 12–16, p. 98, A. S. T. M. *standard*, 1918) are in abstract as follows:

Phosphorus (acid steel), Not over 0.06 per cent.
Phosphorus (basic steel), Not over 0.04 per cent.
Sulphur, Not over 0.05 per cent.
Tensile strength, between 58,000 and 68,000 lb. per sq. inch.
Elongation, min. per cent in 8 in. 1,500,000/tensile strength.

From the above data we have a good idea of the kind of steel in connection with which it was the Committee's first and specific task to investigate welding.

Two kinds of welding are under investigation at present:

1. Fusion welding.
2. Spot welding.

These are totally different kinds of welding. The fundamental difference is that while in fusion welding no pressure is employed, the success of spot welding is entirely dependent upon the application of both heat and pressure. For the spot welding of thick plates, the required pressure is very great.

The main features of each of these two kinds of welding will now be stated:

FUSION WELDING

The term fusion welding is employed to cover gas welding and electric-arc welding.

Gas welding is usually effected by simultaneously fusing with an oxyacetylene flame (1) the material at and near the surfaces which it is desired to join, and (2) some material (which is usually similar in composition) in the form of a rod, the tip of which is subjected to the heat of the flame. The oxy-acetylene flame is directed with one hand and the welding rod is manipulated with the other hand. The operation is illustrated in Fig. 1.

Electric-arc welding may be subdivided into several classes. The two broadest classes are:

a. Carbon-arc welding
b. Metal-arc-welding

In carbon-arc welding, an arc is established between a carbon or graphite electrode (usually a *graphite* electrode) and the two pieces of steel which it is desired to join. This graphite electrode is manipulated with one hand and a welding rod is fed into the weld by the other hand. The operation of carbon-arc welding is illustrated in Fig. 2. The manual activities in carbon-arc welding are seen to be quite similar to those in gas welding. In neither case is it necessary for the material of the welding rod to traverse the arc.[1]

In metal-arc welding, we find a fundamental difference in this latter respect, since in Metal-arc welding of mild steel, the arc, instead of having a graphite electrode for one terminal of the circuit, is established between a steel welding rod (or welding electrode) and the two steel parts requiring to be joined. The operator in Fig. 3 is employing metal-arc welding to build up an incorrectly machined crank-shaft journal. There is always a distance of a matter of a tenth of an inch (2.5 mm.) or more between the end of the welding rod and the work. This distance is bridged by an electric arc. The form in which the steel exists during its passage from one end of the arc to the other is at present the subject of investigation by several independent experimenters.

Their conclusions are awaited with interest. The material cannot pass as a continuous liquid stream, since then there could be no interruptions in the metallic circuit and hence there could be no arc. It can pass as a series of liquid drops, and these can even momentarily short-circuit the arc, the duration of the short-circuit being too brief to be apparent to the operator or ordinary observer unaided by special apparatus. Or the drops can be so minute as to be incapable of effecting a short-circuit. If this should be the case, we can conceive of the metal passing as a stream of finely-divided liquid. Still another possibility is that the steel may pass as a highly-heated gas and condense on the opposite surfaces. It is suggested by physicists that, in its passage through the arc, the steel may undergo instantaneous transformations of which no human knowledge at present exists.

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[1] Both for carbon-arc welding and gas welding, the edges of the parts to be joined sometimes may be so designed as to obviate the need for any additional material; in other words, no welding rod is necessary in such cases.

There would appear to be more of these complex possibilities in metal-arc welding than in gas welding or in carbon-arc welding. Nevertheless, it is precisely metal-arc welding which is at present proving very attractive to engineers. It is too early to return a verdict as to whether this wide-spread tendency toward metal-arc welding is based on sound premises or whether there ultimately may not be a reaction (for certain kinds of work) back to carbon-arc welding. It may be that there has been undue precipitancy in the general stampede which has taken place from carbon-arc welding (which was the first to be developed) to metal-arc welding, which is a later development.

SPOT WELDING

Spot welding, as developed for use in ship construction, consists in bringing into good contact, by hydraulic or pneumatic pressure, over-lapping portions of the plates or parts requiring to be joined, and in sending through the spot of contact a sufficiently large current to heat the plates or parts at this point to a welding temperature. The weld is effected by the combination of pressure and heat.

Several large spot welders have been built. With one of these (which was an experimental machine), sufficient pressure and current were available to weld together three one-inch thick plates. The usual construction of commercial spot welders for use in shipbuilding is similar in general appearance to so-called bull-riveters. The largest spot welder yet built for actual use in ship fabrication has a six-foot (1.8 m.) gap. This outfit is a large stationary machine to which the steel plates and shapes must be brought. It is planned that bulkheads, frames, floors, and other parts shall be constructed with it and shall then be transported by cranes to their places in the ship. This six-foot-gap machine is designed with capacity to weld two three-quarter-inch-thick plates. It provides a pneumatic pressure of 60,000 lb. and a current of 50,000 amperes and welds simultaneously two spots, each of some 1½ inch diameter, in about 30 seconds. With less current a longer time is required, and vice-versa. This particular spot welder, which is shown in Fig. 4, is known as a Duplex Welder. This name is due to the feature that *two* spots are *simultaneously* welded, the current crossing the plate in one direction between two electrodes, and then back again between two other electrodes.

Two transformers, one located on each side of the plate, are comprised in the outfit. The arrangement is indicated, diagrammatically in Fig. 5, in which:

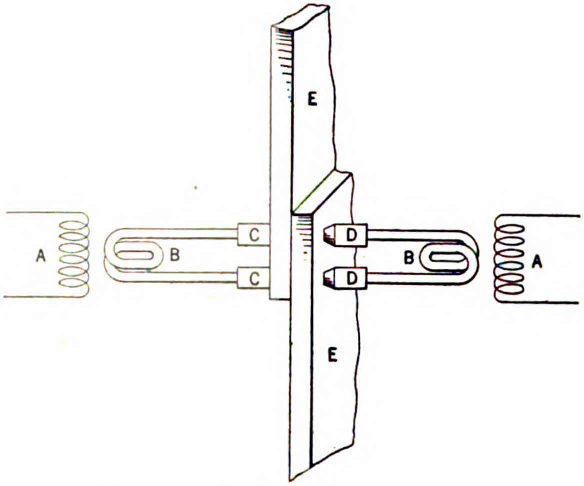


FIG. 5—WIRING DIAGRAM OF DUPLEX SPOT WELDER

A A represents the two primaries.

B B represents the two secondaries (which, in the actual construction, have only one turn each.)

C C and *D D* represent the electrodes between which the current flows and between which the pressure is exerted.

E E represents the two plates to be joined.

The chief object of this duplex feature is to eliminate the large reactance drop of a conducting loop some six feet long and one foot wide when traversed by some 50,000 amperes of 60-cycle current. This amounts to approximately 25 volts. Mr. J. M. Weed, the designer of the machine, reports the interesting fact that the presence in the gap of the plates to be

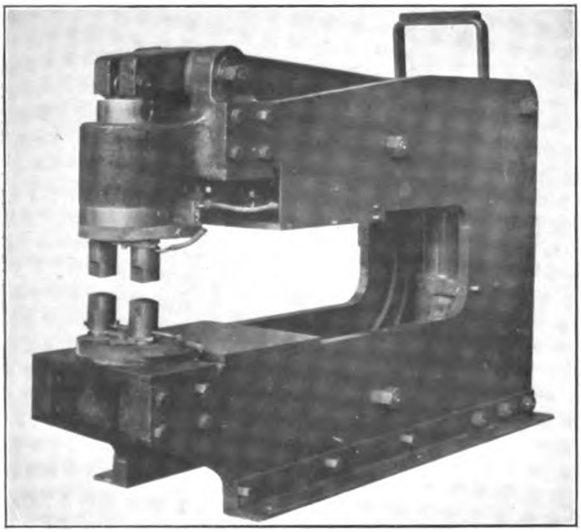
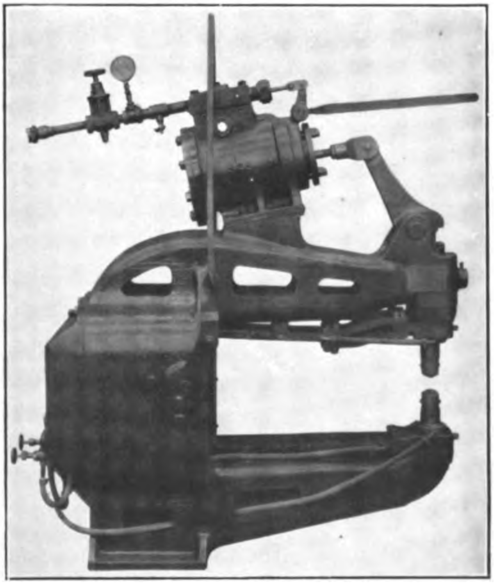


FIG. 4—DUPLEX SPOT WELDER



[HOBART]

FIG. 6—PORTABLE SPOT WELDER WITH 27-INCH GAP

welded, only decreased the current some ten per cent. This six-foot-gap machine weighs six tons.

In some other large spot welders of somewhat reduced size and capacity, the duplex feature is not employed and only one spot is welded at each application of the current. A portable welder of this type and having a 27-inch (68.5 cm.) gap, is shown in Fig. 6. This machine weighs only 2800 lb. (1271 kg.). In this case only one transformer is employed, and the circuit connections are those shown in Fig. 7, in which:

A represents the primary of the transformer.
B represents its secondary.
C and *D* represent the electrodes.
E and *F* represent the two plates to be welded.

In all spot welders for welding thick plates, the electrodes are water-cooled.[2]

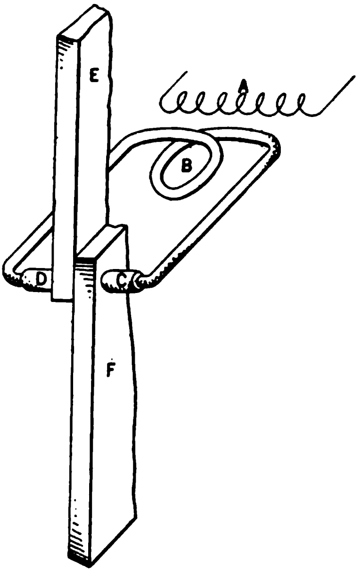


Fig. 7—Wiring Diagram of Portable Spot Welder with 27-inch Gap

When, in the Spring of 1918, Prof. C. A. Adams, of the Welding Committee of the Emergency Fleet Corporation, appointed several of us to be members of a Welding Research Sub-committee, we found ourselves facing a task of great importance and of enormous magnitude. It was desired that our investigations should be directed chiefly to the application of welding in the construction of the hulls of merchant ships. Much interior work on ships was already being performed very successfully with fusion welding and it appeared strongly indicated that the time was ripe for the extension of the application to the hulls of ships, with the prospect of producing work not only fully equal (and probably superior) to that obtained by riveting, but also distinctly quicker and cheaper. At the time a welded barge was already nearly completed in England. The Welding Research Sub-committee ascertained that several American railways had for some time employed fusion welding extensively in routine repairs of locomotives and that a matter of possibly a couple of thousand arc welders were at that time employed by American Railways. The extensive and successful use of fusion welding for locomotive repairs, in itself constituted strong evidence of the ability of such welds to withstand vibration and shock in addition to their proved excellence with respect to tensile strength.

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[2] Excellent discussions of the subject of spot welding and descriptions of several spot welders built for use in ship construction are given in the four following papers in the *General Electric Review*, December, 1918: Research in Spot Welding of Heavy Plates by W. L. Merrill, p. 919; Spot Welding and Some of its Applications to Ship Construction by H. A. Winne, p. 923; An Electrically Welded Freight Car by Jos. A. Osborne, p. 912; Some Recent Developments in Machines for Electric Spot Welding as a Substitute for Riveting by J. M. Weed, p. 928.

Any doubts entertained by the Committee related chiefly to the question of which of many ways in which it had been demonstrated that good fusion welding could be done, was the best way. Furthermore, as regards such mild-steel plates as are employed in the construction of merchant ships, it was soon demonstrated that while sound and quite ductile welds could be depended upon for plates of not over one-half-inch thickness, there was less certainty of good results with plates of greater thickness. But at that time there was no general recognition of the most suitable current to be employed for welding. It was rare to find more than 150 amperes used, even for the heaviest work, and as low as 100 to 125 amperes was found to be frequently employed for welding plates of half-inch thickness.

It now has been quite conclusively shown that stronger and more ductile welds of half-inch-thick plates are obtained by using at least 200 amperes. The author believes that fully 300 amperes should be used for butt-welding three-quarter-inch-thick plates and a matter of at least 400 amperes for one-inch-thick plates. These are some twice as great currents as have heretofore usually been employed in arc-welding plates of these thicknesses.

In view of this subsequent experience, it is clear that the disappointing lack of strength and ductility in certain welds of thick plates made nearly a year ago was a practically certain consequence of using such small currents.

It would be easy to yield to the temptation to enter discursively upon comments and opinions regarding the many points on which experienced welding specialists hold widely divergent opinions. All these specialists are producing thoroughly reliable work, but this is not saying that they are all producing nearly as good work as could be produced under the most appropriate conditions for each case. Indeed, the author's observations lead him to the conclusion that while excellent arc welding is being done on a wide scale, there is a margin for improvement over the present average quality, which, so far as it can be expressed by a sort of resultant of such physical characteristics as:

a. Bending and torsion tests
b. Tensile strength
c. Elongation at fracture

may be assessed as amounting to at least 25 per cent.

The author has attempted to make a list of some of the points which are the subject of discussion, and (while usually not going at much length into the questions), to make reference, in some instances, to the views and evidence on each side of a question. It has been the author's thought that such a summarized presentation might constitute the foundation for an instructive discussion.

The list is as follows:

PAGE
1. Bare and Covered Welding Wire 10
2. Salvaging Welding Wire 10
3. Preferable Kind of Covering for Welding Wire 11
4. Preferable Composition for Bare Welding Wire 11
5. Composition of Metal Deposited in Weld 14
6. Polarity 15
7. Direct-current Versus Alternating-current for Arc Welding 16
8. Periodicity for Alternating-current Arc Welding 16
9. Bare or Covered Electrodes for Alternating-current Arc Welding 17
10. Relative Speeds of Alternating- and Direct-current Welding 17
11. Comparative Quality of Arc Welds Made with Alternating Current and with Direct Current 18
12. Power Factor for Alternating-current Arc Welding .. 18
13. Alternating-current Welding is Essentially a Single-phase Load 19
14. Spot Welding is a Single-phase Load 19
15. Ductility of Arc and Gas Welds 20
16. Respective Fields of Gas and Arc Welding 21
17. Relative Ductility of Welds with Bare and Covered Electrodes 25
18. Speed of Arc Welding 25
19. Suitable Current for Given Cases 27

20. Effect on Arc Welding of Voltage Employed........ 28
21. Preferable Size of Electrodes...................... 28
22. Automatic Machinery for Arc Welding............. 29
23. Carbon Arc Welding.......................... 29
24. Preparation of Welding Edges.................... 30
25. Quality of Overhead Arc Welding.................. 31
26. Number of Layers to be Employed................ 31
27. Rigid vs. Non-rigid Methods of Welding........... 31
28. Consequences of Different Lengths of Arc.......... 32
29. Spot and Arc Welding.......................... 32
30. Condition of Surfaces to be Welded................ 34
31. Preheating, Heat Treatment, and Hammering while Cooling.................................. 34
32. Time Required to Train Welders.................. 34
33. Question of Need for Special Machines for Welding . 35
34. Technique of Testing Welds...................... 35

1. BARE AND COVERED WELDING WIRE

The kinds of electrodes advocated and actually used in the art range all the way from the cheapest fence wire, costing but a few cents per pound (say at present prices, some 10 cents per lb.) up to carefully treated and covered electrodes, certain types of which cost over five times as much as bare electrodes. Some makes of covered electrodes are, however, obtainable at reasonable cost (such as, at present prices, some 20 cents to 25 cents per lb.). One type of electrode must yield results uniformly superior to those obtained with another type in order to afford economic justification for a five-times greater price.

2. SALVAGING WELDING WIRE

As to bare electrodes it is generally considered that uniformity is very essential. An operator may be getting along very nicely but will suddenly come to bad places in the welding wire. Heretofore it has been considered necessary to reject such wire. The claim is now made by some people that by merely dipping the electrode wire in suitable material, it may be salvaged. Thus in the Welding Committee's Specification for Electrode Wire (given at page 573 of this paper) occurs a note to the effect that "If electrodes to the above specification sputter or flow unevenly, they may be dipped in milk of lime (whitewash) before welding. This dipping may be done in quantity on stock on hand and allowed to dry, or the welder may keep a pot of solution on hand into which the electrode may be dipped immediately before welding." This method of salvaging electrode wire was developed by the General Electric Research Laboratory.

Also, it has been demonstrated by Mr. E. Wanamaker that the application, by dipping, of a kind of coating which he has developed (and the precise composition of which he will doubtless contribute to the discussion of this paper), permits of doing good work with electrodes which would otherwise be useless.

3. PREFERABLE KIND OF COVERING FOR WELDING WIRE

With regard to covered electrodes, while some claim that a thin covering obtained by dipping, accomplishes the desired purpose, others contend that it is desirable to provide a thick covering of appropriate material, which, in turn, is suitably impregnated. Moreover, even for covered electrodes, the usual belief is that the greatest care should be given to the composition and quality of the welding wire to which the covering is applied. In other words, it is not generally held that the use of inferior wire salvaged as indicated under (2), will permit of obtaining the best quality of welds. It is important that the covering shall be so designed as to be consumed at a definite rate as compared with the rate of consumption of the enclosed welding wire. A consequence is that any particular gage of *covered* welding wire must be used within rather close current limits.

For *overhead welding* one firm exploiting covered electrodes supplies a special (and additionally high-priced) grade in which the covering is impregnated with a more viscous material than is used for the electrodes which the firm supplies for other welding operations.

4. PREFERABLE COMPOSITION FOR BARE WELDING WIRE

There is a great diversity of practise as to the preferred composition of bare electrodes suitable for welding mild steel plates. As instances of extremes it may be said that amongst widely used electrodes, while one type consists of almost pure iron, other types have nearly 0.2 per cent of carbon and 0.5 per cent of manganese, and still other types run very much higher than this in manganese. This is quite aside from the subject of special compositions for welding high-carbon steel and for welding cast iron. It is anticipated that quantitative measurements will indicate superiority in tensile strength for some

TABLE I.

COMPOSITION OF WELDING ELECTRODES FOR METAL-ARC WELDING

Trade designation of electrode	Carbon	Manganese	Phosphorus	Sulphur	Silicon	Remarks
Page Steel & Wire Co.						
Armco	0.01	0.025	0.005	0.025	0.005	
Wilson Welders & Metals Co.						
Grade, No. 6	0.15 to 0.23	0.60 to 0.75	less than 0.04	less than 0.04		Also 0.25 per cent copper.
Grade, No. 9	0.30 to 0.40	about 1.00	less than 0.04	less than 0.04		
Grade, No. 8	0.17 to 0.22	0.30 to 0.45	less than 0.04	less than 0.04		
Grade, No. 17	0.10	0.30 to 0.45	0.06	0.06		
Quasi Arc Co.	0.08 to 0.12	0.45 to 0.55	0.00 to 0.06	0.00 to 0.06	0.05 to 0.08	Flux covering of blue asbestos fibre (Crocodilite) enclosing percentage of aluminum or other metal in form of fine wire capable of giving strong reducing action.
Roebling Co.	0.16	0.56	0.032	0.024	0.016	
Toncan wire	0.10	0.16	0.01	0.046	trace	
Electric Arc Cutting & Welding Co.	0.25	0.30	0.05	0.05	0.05	
Siemund Wenzel Co.	0.10 and under	0.30 to 0.50	0.05 and under	0.05 and under	trace	
Norway-iron Wire	0.05	0.02	0.025	0.007	0.08	
Double Arc Co., of England	0.085	0.35	.....	0.054	0.108	Flux covered.
T. Scott Anderson Co., of England	0.057	0.32	.....	0.026	0.014	Flux covered.
E.A.Jones & Co.,of England	0.22	0.25	0.001	0.026	0.024	Nickle-plated and flux covered.
Engineering and Equipment Co., of England	0.12	0.51	.....	0.08	0.016	Flux covered.
Central Steel & Wire Co.						
Swedox	0.05	0.18	0.04			
The Spencer Wire Co.						
Basic open-hearth steel electrode	00.06	0.12 to .20	0.013 and under	0.03 and under		

compositions and superiority in ductility for other compositions. Mr. R. E. Wagner has exhibited some very ductile welds made with electrodes containing small percentages of magnesium and of boron sub-oxide.

It is only within the last few months that there have been available any specifications for use in establishing the merits of welding wire. These are now available in the Welding Committee's specification setting forth a "Standard Procedure for Testing Welding Electrodes." This specification, which is given in Appendix A to this paper, was prepared by the Welding Research Sub-committee in collaboration with Prof. H. L. Whittemore representing the Bureau of Standards and with representatives of manufacturers of welding electrodes.

In Table I are given the compositions of various electrodes in current use. Prior to publication, the data in this Table was submitted to the manufacturers concerned, who, in six instances, improved the opportunity to correct the data to conform with their latest practise. The American Steel and Wire Co. has requested the omission from the accompanying Table of any analyses of electrodes which it has furnished for arc welding. This is for the reason that material has been supplied to a large number of users, and varies considerably in analyses in accordance with the ideas of the purchasers. There does not as yet seem to be an agreement as to the most advantageous chemical composition for electrodes, and the company is not prepared either from observations of the results obtained by its customers or from its own experimental work to make a definite recommendation.

The Welding Committee has issued the following Specification for Electrode Wire for Electric Welding. The specification was prepared under the immediate direction of Mr. Herman Lemp.

SPECIFICATION FOR ELECTRODE WIRE FOR METAL-ARC WELDING IN CONNECTION WITH MILD STEEL

Welding Committee Emergency Fleet Corporation

REVISED TO DECEMBER 20, 1918

(Note:—This wire may or may not be covered)

1. *Chemical Composition*

Carbon	Not over 0.18 per cent.
Manganese	" " 0.55 " "
Phosphorus	" " 0.05 " "
Sulphur	" " 0.05 " "
Silicon	" " 0.08 " "

2. *Sizes and Weights*

Diameter, in mils	Diameter, in fraction of an inch	Pounds per 100 ft.	Feet per 100 lb.
125	$^1/_8$	4.16	2400
156	$^5/_{32}$	6.51	1535
188	$^3/_{16}$	9.37	1066

(Allowable tolerance 6 mils plus or minus)

3. *Material.* The material from which the wire is manufactured shall be made by any approved process. Material made by *puddling process not permitted.*

4. *Physical Properties.* Wire to be of uniform homogeneous structure, free from oxides, pipes, seams, etc., as proved by photomicrographs.

5. *Workmanship and Finish.* (*a*) Electric welding wire shall be of the quality and finish known as the "Bright Hard" or "Bright Soft" finish—"Black Annealed" or "Bright Annealed" wire shall not be supplied.

(*b*) The surface shall be free from rust, oil or grease; a slight amount due to lubrication during last drawing is permissible.

6. *Tests.* Electrodes must, before shipment or after delivery, show good commercial weldability when tested by an experienced arc welder. The electrode material shall flow smoothly in relatively small particles through the arc without any detrimental phenomena.

Note: If electrodes to above specifications sputter or flow unevenly, they may be dipped in milk of lime (whitewash) before welding. This dipping may be done in quantity on stock on hand and allowed to dry, or welder may keep a pot of solution on hand into which the electrode is dipped immediately before welding.

7. *Delivery, Packing and Shipping.* Electrodes shall be furnished in straight lengths of either 14 inches or 28 inches, put up in bundles of 50 pounds or 100 pounds as ordered. Each bundle shall be wrapped in heavy paper securely wired and marked on one end showing diameter in mils, trade name and grade of wire.

5. COMPOSITION OF METAL DEPOSITED IN WELD

A few analyses have been made of chemical compositions of the metal deposited in the weld. Results of the analyses of four sets of electrodes before and after the metal was deposited are quoted below from the Westinghouse chapter in Major Caldwell's report, published by the Emergency Fleet Corporation in 1918. To these results are added analyses of Toncan wire as supplied to the author by Mr. R. E. Wagner.

ANALYSES OF ELECTRODE—PER CENT OF IMPURITIES

	Carbon	Manganese	Phosphorus	Sulphur	Silicon
Roebling	0.16	0.56	0.032	0.024	0.016
Norway	0.049	0.021	0.025	0.007	0.08
C. R. S.	0.11	0.72	0.097	0.123	0.011
H. R. S.	0.13 to 0.17	0.50	0.012	0.045	0.011
Toncan	0.10	0.16	0.010	0.046	trace

ANALYSES OF DEPOSITED METAL—PER CENT OF IMPURITIES

	Carbon	Manganese	Phosphorus	Sulphur	Silicon
Roebling	0.05	0.18	0.031	0.036	0.011
Norway	0.05	0.018	0.020	0.072	0.011
C. R. S.	0.05	0.11	0.086	0.072	0.011
H. R. S.	0.14	0.14	0.012	0.039	0.011
Toncan	0.042	0.081	0.019	0.026	0.000

It is notable that most of the carbon and manganese is burned out in traversing the arc.

6. POLARITY

For carbon-arc welding, the standard practise is to connect the graphite electrode to the negative terminal. Mr. Wagner states as his experience that it is very difficult to weld with the carbon arc when the polarity of the carbon is positive. He states it to be almost impossible to direct the heat to the point desired and the welding qualities of the arc under this condition are very poor. He concludes: "Our experience has taught us that it is next to impossible to weld with a carbon arc unless the work is positive and the electrode negative."

For metal arc welding with bare wire, the electrode is usually connected to the negative terminal, but instances occur of bare welding wire which works best when the opposite polarity is employed. Also for some particular sizes and sorts of welds best results are sometimes obtained by a reversal of the polarity. With electrodes heavily covered with flux, the positive terminal is almost always connected to the electrode. Plenty of more or less plausible reasons for these differences have been offered on various occasions. On careful reflection none of these reasons prove particularly satisfying. Amongst other considerations the fact of the entire practicability of arc welding from an alternating current circuit and of overhead welding have to be taken into account in judging some of these explanations. As yet, we have no satisfactory hypothesis as to what goes on in the welding arc.

7. DIRECT CURRENT VERSUS ALTERNATING CURRENT FOR ARC WELDING

While up to rather recently it had usually been contended that arc welding required a direct-current supply, there are now many advocates of alternating current.

Mr. E. H. Jones in the course of the discussion of Major James Caldwell's paper entitled "Notes on Welding Systems" read on Jan. 22, 1918, before the Institution of Engineers and Shipbuilders in Scotland, stated: "He would like to take this opportunity of drawing attention to the undoubted merits of alternating current for arc welding. For some reason which he was unable to fathom, the general impression was that direct current was superior to alternating for arc welding, but as a matter of fact he found that alternating current was far superior to direct current, and he would recommend the use of alternating current on every possible occasion. Apart entirely from the capital outlay needed, which was vastly higher in the case of direct current, the control of the current was much easier to effect. . . . He estimated that the amount of current which would be necessary to feed 20 operators with direct current would suffice to feed 28 with alternating current."

Mr. R. E. Wagner's experience is as follows: "Electric welding may be done with alternating current as well as with direct current. It is a little more difficult to hold the arc, but this simply resolves itself into a matter of practice. Men who have been regularly doing arc welding with direct current, very quickly learn how to handle the alternating current arc."

At present there is no agreement as to the applicability of alternating current to carbon arc welding.

8. PERIODICITY FOR ALTERNATING-CURRENT ARC WELDING

Amongst the advocates of the use of alternating current, there is no agreement with reference to the periodicity. Although it is generally maintained that arc welding is only thoroughly practicable with as high a periodicity as fifty or sixty cycles per second, there is, on the other hand, expression given to the opinion that the use of twenty-five cycles, or less, is equally satisfactory. In October, 1918, Mr. R. E. Wagner reported to the Welding Research Sub-committee, that he had found from his tests that alternating current for arc welding could be used with a frequency as low as 12½ cycles and as high as 500 cycles. Mr. Wagner states that while there is no difficulty at either of these extreme periodicities, the arc is more readily held at 500 cycles than at 12½ cycles.

9. BARE OR COVERED ELECTRODES FOR ALTERNATING-CURRENT ARC WELDING

While some maintain that arc welding with alternating current is only at its best when flux-covered electrodes are used, it appears to have been conclusively demonstrated by others that excellent results are being obtained under commercial conditions with bare electrodes and an alternating-current supply. A novice can more quickly learn to weld from an alternating-current supply if he employs flux-covered electrodes. But if he can ultimately learn to weld just as rapidly and successfully with bare electrodes, the difficulties in the initial stages of his education should not be regarded as being of much consequence. Mr. Wagner finds that when welding with alternating current, "manipulation may be simplified in many cases by treating the electrode with a thin coating of ordinary lime."

10. RELATIVE SPEEDS OF ALTERNATING-CURRENT AND DIRECT-CURRENT ARC WELDING

Some contend that alternating-current welding is slower. As an instance of a diametrically opposite experience, the following recently received record of test of a certain electrode may be quoted:

"Its operation on 140 amperes, 115 volts alternating current is very good. It also works satisfactorily on 130 amperes, 75 volts direct current, but the metal flows more slowly on direct current than on alternating current."

The record concerning another type of electrode tested on the same occasion, reads as follows:

"This electrode was tried on 5/16 in. plate, 120 amperes, direct current, 75 volts. Its operation is satisfactory. It also works satisfactorily at 140 amperes, alternating current, 115 volts, but its operation on alternating current is not quite as good as on direct current."

Mr. R. E. Wagner, who has had much to do with the development of both kinds of welding, states that "on the average the speed of welding with alternating current and direct current is about the same. We have had cases where alternating current is faster, and vice versa."

11. Comparative Quality of Arc Welds Made With Alternating Current and with Direct Current

It is contended that the greater difficulty of maintaining an alternating-current arc (involving the necessity of acquiring the skill to hold a very short arc,) entails as a consequence that an alternating-current weld is of superior quality. An experienced observer reports his experience as follows:

"Tests made have demonstrated conclusively that it is possible to do as good, or perhaps better, welding with alternating current as with direct current. No very decided difference has been noticed between welds made with alternating current and those made with direct current, but the welder who did most of the alternating-current welding says that in his opinion the alternating-current welds are better than the direct-current welds. This same opinion has been expressed by the machinist who made repairs on a small tank welded with alternating current. He said that the weld metal was better, more dense, and had fewer blowholes than a direct-current weld."

But an opinion from another authority of great experience in arc welding is as follows:

"As regards the strength of an alternating-current weld there is not the slightest doubt that a greater strength can be gotten on a test piece if that is all the work the man is going to do for some time. The facts, however, are that as the man's hand becomes fatigued in holding the alternating-current arc, his consequent breaking of the arc becomes more frequent, which means less strength in the weld, because every time the arc is broken, a bad spot is left in the weld."

12. Consideration of the Power Factor for Alternating-current Arc Welding

A view presented with considerable persistency is that the low power-factor associated with alternating-current welding leads to capital and operating costs offsetting any advantages. One answer made is to the effect that since for ship welding on an extensive scale, motor-generators are required, this only affects the generator and its circuit and does not affect conditions as regards the motor or the circuit from which it is supplied.

13. Consideration of the Circumstance that Alternating-current Arc Welding is Essentially a Single-phase Load

Similar considerations are involved in regard to the necessity of providing for the characteristics of a single-phase load. It is well known that single-phase motors and generators are much heavier, more expensive and less efficient than polyphase motors and generators. With 30 or 40 arc welding outfits distributed fairly evenly on the different phases of a polyphase system, the load would be sufficiently balanced to be satisfactory, but this would correspond to an unusually large welding installation. In most cases it will be necessary to arrange for the welding to constitute a single-phase load and to make adequate provision to obtain satisfactory service with this condition.

Regarding the possibility of improving the power factor, Mr. W. S. Moody makes the following very suggestive statement.[3]

"Where a number of arcs are to be used within a reasonable distance of each other, the series system may be used. In this arrangement the secondary of an ordinary constant-current transformer supplies current to the primary of all the welding transformers in series. The individual transformers insulate the welding apparatus from the series circuit and transform from the series current to current of proper value for the arc. In this case the inherent reactance of the series transformer is low, but other features of the design are the same as those discussed above. The power factor of such a system can be safely made much higher than where individual arcs are operated in multiples from constant potential circuits."

14. Spot Welding is a Single-phase Load

Mr. J. M. Weed, who has had a great deal of experience with large spot welders, has kindly written the following paragraph on this subject:

"For welding plates from 3/8 to 3/4 in. in thickness, the single-phase currents required would be from 30,000 to 50,000 amperes and the kv-a. required at 60 cycles would range between 300 and 900 at power factors of from 0.35 to 0.50. These low

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[3] *General Electric Review* (December, 1918) p. 937.

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16. RESPECTIVE FIELDS OF GAS AND ELECTRIC ARC WELDING

On this subject, under date of Oct. 22, 1918, Mr. R. P. Jackson, reports to the Welding Research Sub-Committee as follows:

"With reference to the comparative uses or fields of gas and electric-arc welding which came up at the last meeting, it was thought it might be well for some of us to express our opinions on the matter based on our experience with both kinds of welding. In general, we have found gas welding to be more satisfactory for thin material, say 1/8 inch and under, and for general repair work, particularly where various kinds of steel and cast iron are involved. For example, if repairs have to be made on broken machinery, lugs rebuilt, pieces attached to high-carbon steel and work of this character, then the gas-welding methods are superior and the extra cost not ordinarily prohibitive. When it comes, however, to depositing a large amount of metal and welding up structural steel or plates of 1/4 inch thickness and upward, the results obtained by the ordinary direct-current arc with the metal electrode are at least equal to the gas welding work and certainly cheaper. In general, too, the finish of gas welding is more regular and better looking and where that is a consideration it may give a preference to gas. In fact, in the Westinghouse factory at East Pittsburgh, there has been considerably more gas work done than electric, but the electric arc welding is on the increase, not so much in displacing gas as in displacing riveting."

A view taken from a gas welding publication is as follows:

"The arc process is chiefly used for filling up blow holes in large steel or iron castings and building up worn surfaces which have not to be machined. With this process the results obtained are somewhat uncertain, and it is generally conceded, apart from the vital question of cost, that fusion produced by the burning of gases is to be preferred to the electric process. Welds made by the electric process are sometimes rough, hard, brittle and unworkable—in most cases this is highly objectionable, but not always so. With any fusion method of welding, annealing of the metal adjacent to the weld is desirable. It is impossible to do this annealing with an electric welder, but with gas welding the blow-pipe flame can be used for heating up the metal surrounding the welded part, and also for heating metal away from the weld, so as to counteract any strains that may be set up in the piece as the weld cools off. There are certain classes of work for which electric welding is the most suitable system, and, on the other hand, there are many classes of work where it would be most impractical, and which can be done satisfactorily only with gas welding. For general workshop use, a gas welding outfit is far better, not only because of its greater economy in installation and operation, but also because of its wider range of usefulness."

In the absence of any experience to the contrary this latter view appears fairly plausible, and it is natural that it should have received wide acceptance. But an enormous volume of experience in arc welding has gradually accumulated and it controverts the correctness of the view. Unfortunately the experimental data available on the subject of *Gas Welding* is surprisingly meagre. The Welding Research Sub-Committee has concluded that there is practically no test data from which it can draw any safe generalizations as to the mechanical characteristics of *gas welds*, and that it will be necessary to embark upon its own investigations to obtain suitable data.

Gas welding was an established art before there was any large amount of electric welding. This was still the state of affairs in England until shortly before the author was there in the autumn of 1917. But the war conditions had occasioned in England such a shortage of supplies of oxygen and carbide that the Government, as a war measure, practically forced the wide substitution of arc welding for gas welding. The British Government, in entering upon this policy, had relatively little concern as to the comparative merits of the two methods except in so far as that any merit or advantages found to be associated with arc welding would naturally assist in bringing about its use in place of gas welding.

It was, however, with considerable surprise that it was ascertained that the true economic field for arc welding as compared with gas welding was a very wide one, and that, simply due to inertia and tradition, engineers had been continuing in the contrary belief. Major James Caldwell, of the Admiralty Controller's Department, had wide responsibilities in this task of substituting arc welding as rapidly and generally as possible. Major Caldwell provided the author with the results of his investigations into the relative cost of gas and metal-arc welding. These results, which correspond to conditions in December, 1917, are set forth in Table II.

From Table II it is seen that metal-arc welding was found

TABLE II.—COMPARATIVE COSTS OF WELDING BY OXYACETYLENE AND METAL-ARC WELDING

Thickness of metal, inches	Oxyacetylene					Metal-Arc					Oxyacetylene		Metal-Arc	
	Gas per hour		Cost for gas per foot run pence	Iron wire for filling, pence	Labor per foot run	Power per foot run			Labor per foot run, pence	Cost of electrodes per foot run, pence	Feet run per hour	Total cost per foot run, pence	Feet run per hour	Total cost per foot run, pence
	Cxygen, cubic feet	Acetylene, cubic feet				Volts	Amp.	Kw.						
1/16	3	2.0	0.116	0.131	0.40	100	30	0.075	0.3	12 in. No. 12 = 1.2	30	0.647	40.0	1.575
1/8	9	6.3	0.77	0.196	0.856	100	75	0.312	0.5	18 in. No. 12 = 1.8	14	1.822	24.0	2 612
3/16	13	9.0	1.72	0.262	1.33	100	100	0.50	0.6	24 in. No. 10 = 2.64	9	3.312	20.0	3.74
1/4	17	13.0	2.70	0.250	1.50	100	140	0.70	0.6	22 in No. 8 = 3.6	8	4.45	20.0	4.90
5/16	27	16.0	4.21	0.327	1.714	100	110	1.10	1 2	12 in. No. 10 18 in. No. 8 } = 4.02	7	6.25	10.0	6.32
3/8	34	24.0	6.82	0.458	2.00	100	120	1.61	1.61	18 in. No. 10 24 in. No. 8 } = 5.58	6	9.278	7.4	8.802
7/16	41	29.0	9.90	0.655	2.40	100	120	2.00	2.0	24 in. No. 10 36 in. No. 8 } = 8.04	5	12.955	6.0	12.04
1/2	48	34.0	14.50	0.786	3.00	100	120	2.40	2.4	30 in No 10 42 in. No. 8 } = 9.6	4	18.286	5.0	14.40

Labor taken at 1 shilling per hour.
Oxygen taken at ½ pence per cu. ft.
Acetylene taken at 1 pence per cu. ft.
Iron for filling taken at 0.131 pence per ft.
The above figures are based on the British Oxygen Co. standards.

Labor taken at 1 shilling per hour.
Current taken at 1 pence per B.O.T. unit.
Electrodes, No. 10, 1.32 pence per ft.; No. 8, 1.8 pence per ft.; No. 12, 1.2 pence per ft.

to be a faster process for all thicknesses of steel. The British Admiralty results furthermore indicate the economic field for the two methods. The verdict from the data in the Table is in favor of gas welding for thin plates and of electric-arc welding for thick plates. But the comparison is based on the very high cost of electrodes set forth below:

Standard wire gauge	Cost in cents per foot	Ft. per pound of contained iron wire	Cost in cents per pound
Number 8	3.6	15	54
Number 10	2.6	23	60
Number 12	2.4	35	84

By substituting a typical American price for labor and substituting the cost of bare electrodes, such as are used with entire success in America, in place of the cost of flux-covered electrodes of the expensive type employed in arriving at the results set forth in the Table, the revised results show a lower cost for arc welding than for gas welding for all thicknesses above $^1\backslash_{16}$ inch. The question of the quality of the weld is another matter, but judging from the general reputation of the work of all sorts done by gas welding and by metal-arc welding, they are both thoroughly reliable. No more exact comparison can be made till we have carried through to completion, really elaborate tests of gas welds in order to permit of making a sound comparison with the large amount of research data already obtained with metal-arc welds.

In response to a request for his opinion as to the respective fields for gas and metal-arc welding, Mr. R. E. Wagner, writes as follows: "The present well-tried field for metal-arc welding is confined entirely to welding plates and forms, and a great deal of work has been done on plates varying in thickness from 1/16 in. to ¾ in. Up to 1/8 in. plates, the cost of gas and electric welding is about the same. Beyond this, the cost is in favor of the electric process. No difficulty is experienced in machining electric welds made with the metallic electrode. While it is recognized that the electric-welded-in material will not stand bending equal to that of the plate in which it is deposited, it is on the average equal to gas-deposited material in this respect."

17. RELATIVE DUCTILITY OF ARC WELDS MADE RESPECTIVELY WITH BARE AND COVERED ELECTRODES

By some authorities, ductility is believed to be most readily obtained by employing flux-covered electrodes. On the other hand, the Committee has knowledge of several kinds of bare electrodes of various compositions which, in competent hands, make reasonably ductile welds.

18. SPEED OF ARC WELDING

All sorts of values are given for the speed, in feet per hour, with which various types of joints can be welded. Operators making equally good welds have widely varying degrees of proficiency as regards speed. Any quantitative statement must consequently be of so guarded a character as to be of relatively small use. In general, and within reasonable limits, the speed of welding will increase considerably when larger currents are employed. It appears reasonable to estimate that this increase in speed will probably be about 25 to 35 per cent, for high values of current. This increase is not directly proportional to the current employed because a greater proportion of time is taken to insert new electrodes and the operator is working under more strenuous conditions. Incidentally, the operator who employs the larger current will not only weld quicker but the weld will have also better strength and ductility.

On this point Mr. Wagner writes as follows: "I would not say that speed in arc welding was proportional to the current used. Up to a certain point ductility and strength improve with increased current, but when these conditions are met, we do not obtain the best speed due to increased heating zone and size of weld puddle. Speed may fall off when current is carried beyond certain points."

In a research made by Mr. William Spraragen for the Welding Research Sub-Committee on several tons of half-inch-thick (12.7 mm.) ship plate, the average rate of welding was only two feet (0.6 m.) per hour. Highly skilled welders were employed but they were required to do the best possible work, and the kinds of joints and the particular matters under comparison were very varied and often novel.

However, in the researches carried on by Mr. Spraragen it was found that about 1.9 pounds (0.8 kg.) of metal were deposited per hour when using a 5/32 in. (3.9 mm.) bare electrode and with the plates in a flat position. The amount of electrodes used up was about 2.7 pounds per hour, of which approximately 16.5 per cent was wasted as short ends and 13 per cent burnt or vaporized, the remainder being deposited at the speed of 1.9 pounds per hour mentioned above.

For a 12-foot-cube tank of half-inch-thick steel welded at Pittsfield, the speed of welding was 3-feet per hour. The weight of the steel in this tank was 16,000 lb. and the weight of electrode used up was 334 lb. of which 299 lb. was deposited in the welds. The total welding time was 165 hours corresponding to using up electrodes at the rate of just 2 lb. per hour. The total length of weld was 501 feet, the weight of electrode used up per foot of weld thus being 0.60 lb. The design of this tank comprised eighteen different types of welded joint. Several different operators worked on this job and the average current per operator was 150 amperes.

For the British 125-foot-long Cross-Channel Barge for which the shell plating was composed of ¼-in. and 5/16-in. thick plates, in Mr. H. Jasper Cox's paper read before the Society of Naval Architects on Nov. 15, 1918, and entitled "The Application of Electric Welding to Ship Construction" it is stated that: "After a few initial difficulties had been overcome, an average speed of welding of seven feet per hour was maintained including overhead work which averaged from three to six feet per hour."

In a report appearing on page 67 of the Minutes and Records of the Welding Research Sub-Committee for June 28, 1918, Mr. O. A. Payne, of the British Admiralty, states: "A good welder could weld on about one pound of metal in one hour with the No. 10 Quasi-Arc electrode, using direct current at 100 volts. An electrode containing about 1½ ounces of metal is used up in about three minutes, but this rate cannot be kept up continuously."

The makers of the Quasi-Arc electrode publish the following data for the speed of arc welding in flat position with butt joints, a 60 degree angle and a free distance of ⅛ inch.

Thickness of Plates	Speed in Feet per Hour
⅛ in.	30
¼ in.	18
½ in.	6
1 in.	1.3

I cannot, however, reconcile the high speed of welding ½-inch plate published in this report as 6 ft. per hour, with the report given above by the British Admiralty that a good welder deposits one pound of metal per hour with Quasi-Arc electrode. If the rate given by the manufacturer is correct, it would mean that about four pounds of metal were deposited per hour. On this basis the rate must have been computed on the time taken to melt a single electrode and not the rate at which a welder could operate continuously, allowing for his endurance and for the time taken to insert fresh electrodes in the electrode holder and the time taken for cleaning the surface of each layer before commencing the next layer.

From his observations the author is of the opinion that a representative rate for a good welder lies about midway between these values given respectively by Mr. Payne and by the makers of the Quasi-Arc electrode, say for half-inch plates some two pounds per hour. This, it will be observed, agrees with Mr. Spraragen's experience in welding up some six tons of half-inch ship plate with a dozen or more varieties of butt joint and Mr. Wagner's results with the eight-ton tank. Even this rate of two pounds per hour is only the actual time of the welding operator after his plates are clamped in position. This preliminary work and the preparation of the edges which is quite an undertaking, and requires other kinds of artisans, accounts for a large amount of time and should not be underestimated.

The practise heretofore customary of stating the speed of welding in feet per hour has led to endless confusion as it depends on type of joint, height of weld and various details. A much better basis is to express the speed of welding in pounds of metal deposited per hour. Data for the pounds of metal deposited per hour are gradually becoming quite definite. The pounds of metal per foot of weld required to be deposited can be readily calculated from the drawings or specifications. With the further available knowledge of the average waste in electrode ends and from other causes, the required amount of electrode material for a given job can be estimated.

19. SUITABLE CURRENT FOR GIVEN CASES

For a given type of weld, for example, a double Vee weld in a one-half-inch-thick ship plate, it was found that in the summer of 1918, while some operators employed as low as 100 amperes, others worked with over 150 amperes. Some, in making such a weld, employed electrodes of only 1/8 in. diameter and others preferred electrodes of twice as great cross-section. For the particular size and design of weld above mentioned, the Welding Research Sub-Committee has since had welds made with from 200 to 300 amperes. The conclusion appears justified that the preferable current for such a weld is at least 200 amperes. If the weld of the half-inch-thick plate is of the double-bevel type, some 50 amperes less current should be used for the bottom layer than is used for the second layer, if two layers are used. For three-quarter-inch-thick plates, the most suitable welding current is some 300 amperes. This is of the order of twice the current heretofore usually employed for such a weld.

Mr. Wagner writes: "We have made a number of tests to determine the effect of varying current on the strength of the weld. Tests were made on a ½-in. plate with current values as follows: 80, 125, 150, 180, 220, 275, and 300 amperes. These tests show improvement in the tensile strength and bending qualities of welds as the current increases. The speed of welding increases up to a certain point and then decreases."

20. EFFECT ON ARC WELDING OF VOLTAGE EMPLOYED

Mr. Wagner reports as follows: "We have made a number of tests to determine the influence of variable voltages on the strength and character of electric welds. The experiments were made welding ½ in. plate with 150 amperes held constant and voltage varying as follows: 40, 75, 100, 125, 150, 200 and 225 volts.

"This test demonstrates that there is no material difference in the tensile strength, bending qualities or the appearance of the welded-in material. There is this advantage, however, in the higher voltage, that variations in the strength of the arc do not materially affect the value of the current.

"A curve-drawing ammeter was installed on the welding circuit which showed variations in current at 75 volts, but at 150 volts the current curve was practically a straight line."

21. PREFERABLE SIZE OF ELECTRODE

On certain railways, a single diameter of electrode is employed independently of the size or shape of the plates or parts being welded. The experience of other people leads them to make use of several different sizes of electrodes according to the size of the job and the type of joint. Present British practise appears to be to use such a size of electrode as to have a current density of some 4000 to 6000 amperes per square inch. The investigations of the Welding Research Sub-Committee indicate that at least 10,000 to 12,000 amperes per square inch is suitable for electrodes of 1/8 in. and 5/32 in. diameter and well up toward 10,000 amperes per square inch for electrodes of 3/16 in. and 3/4 in. diameter.

22. AUTOMATIC MACHINERY FOR ARC WELDING

Several firms are developing machinery for feeding the electrode automatically. Such machinery appears to be capable of making excellent welds at higher speeds than are attainable by hand feeding.

23. CARBON-ARC WELDING

With the advent of metal-arc welding there has been a tendency to neglect the carbon-arc method. It is quite possible that this attitude is not justified for not only is there now a definite field where the carbon-arc method is advantageous but developments in the art may greatly extend its application.

It is generally agreed that the carbon-arc method is not applicable to vertical and overhead welding, which is, of course, a serious handicap in ship-hull work. The majority opinion of competent observers (with, however, some emphatic dissenting views) appears to indicate that carbon-arc welding is not as reliable as metal-arc welding in ordinary welding, because:

a. Carbon is carried into the deposited material thus reducing its ductility.

b. It is more difficult to obtain good fusion on account of overlapping of deposited metal on the original metal.

c. It is more difficult to manipulate and thus requires greater skill.

d. It is a much hotter arc which means greater discomfort to the operator and therefore lower efficiency.

e. Greater cooling stresses are developed because larger areas of adjacent metal are heated.

On the other hand, it is contended by some that carbon-arc welding can be developed to the point where these objections will no longer exist and thus gain the advantages of this method, the principals of which are:

a. No preparation of the abutting edges is necessary.

b. Greater rate of deposition of metal and therefore greater speed of welding, particularly in heavy work.

c. Probable greater adaptability to automatic welding.

It should be stated that there is very general agreement as to the superiority of the carbon arc over the metal arc for heavy work where strength is not so important, especially cast-iron welding and the filling of holes in iron and steel castings.

24. Preparation of Welding Edges

British practise permits the use of smaller angles when the edges of the plates are Veed, than accords with American traditions. If the smaller angles give welds which are equally satisfactory in all respects, the decreased amount of electrode material required, the decreased consumption of electricity, and the increased speed are advantages not to be overlooked; but obviously the matter requires careful investigation. American practise which, up to recently, has been with a very wide angle, appears to have required the consumption of about twice as great a weight of electrode as British practice with the smaller angle. The urgent importance of determining whether the use of the smaller angle involves any sacrifice in quality is evident. There is already considerable basis for the belief that actually better results attend the employment of a smaller angle of bevel when a suitably large current is used. A shoulder in place of the heretofore commonly used sharp bottom edge of the bevel, also constitutes a material gain not only in the saving in welding material, but also in the quality of the weld.

TABLE III.—TIME, METAL, AND CURRENT USED WITH WELDS OF DIFFERENT BEVELS

	Angle of Bevel Used, in Degrees			
	15	30	45	60
Amperes	160.	145.	118.	125.
Weight of electrode used up (lb.)	2.56	3.83	4.63	6.63
Weight of metal deposited (lb.)	1.70	2.55	3.65	5.08
Weight of metal wasted (lb.)	0.86	1.28	0.98	1.55
Pounds deposited per hour	1.82	1.61	1.82	1.81
Feet welded per hour	3.22	1.90	1.50	1.07
Circuit kilowatts	9.91	9.00	7.68	8.25
Kilowatt-hours per foot of weld	3.10	4.70	5.10	7.70

Mr. Wagner states that at Pittsfield they have long adopted the practise of using a 30-degree bevel for plate edgings and that they find it satisfactory for all thicknesses up to ¾ in. He states that this angle gives sufficient room for depositing the metal, reduces the time to weld and the amount of metal deposited.

In one of Mr. Spraragen's researches, various angles of bevel were used. Although the physical tests have not yet been made we can gain from Table III valuable lessons on the time, amount of metal, and electricity consumed for these different angles of bevel. The "free distance" in each case was ⅛ in. and the welding was done in a flat position with 5/32-in. bare electrodes. In each case the weld had a length of three feet.

25. QUALITY OF OVERHEAD ARC WELDING

The British Admiralty regards overhead welding as too inferior and too expensive to be employed when it can possibly be avoided. In America a large amount of overhead welding is done in railway shops and it is claimed that it is simply a matter of training operators to the required degree of proficiency.

26. NUMBER OF LAYERS TO BE EMPLOYED

Good progress is being made in obtaining knowledge of the relative characteristics of welds made with different number of layers and of the most suitable current and the most suitable size and type of electrodes to employ for each layer. The tendency is toward the use of at least two layers for half-inch-thick plates, and three layers for three-quarter-inch-thick plate.

27. RIGID VS. NON-RIGID METHODS OF WELDING

On this question it is more a matter of determining the conditions essential to obtaining good results with whichever of the two methods is most appropriate for each particular purpose.

The term *rigid* is applied to the process of arc welding, in which the two parts to be joined by welding are, prior to welding, held rigidly by bolting or clamping or by a series of preliminary tack-welds distributed at various points. The rigid plan is the most obvious for welding the hull plates of ships but its critics claim that the resultant joints are deficient in ductility due to the presence of internal stresses. It is considered that by suitably arranging the order of welding it is practicable to so distribute the heat as to avoid these stresses. At any rate, there are many alternative orders of procedure in making welds by the rigid method and elaborate researches should be made to ascertain the procedure which will yield the best result.

The non-rigid method consists in placing at a slight angle to each other the two plates to be welded. As the welding operation progresses along the seam the angle gradually closes and when the weld is completed the width of the welded seam is equal throughout its extent. Such welds are generally considered to be very free from internal stresses, and hence more ductile.

28. Consequences of Different Lengths of Arc

The metal arc is much shorter than the carbon arc. As a result the metal arc weld has the advantage that there is less opportunity for oxygen and nitrogen to gain access to the weld and so far as relates to this feature the metal arc weld should be better. But with the carbon arc the added metal does not traverse the arc, the tip of the welding rod being held down close to the surface on which it is to be deposited. This may render the deposited material less subject to contamination in carbon arc welding than in metal arc welding since it has not traversed the arc.

Coming to the exclusive consideration of metal-arc welding, the greater the welding current the less is the area represented by the cylindrical surface of the arc per pound of metal traversing the arc, and consequently the less should be the contamination by oxygen and nitrogen from the surrounding air. So far as this circumstance is concerned, the greater the welding current, for a given case, the greater should be the ductility of the joint. On the other hand, it seems probable that even the most skilful operators will be unable to hold quite so short an arc with the larger current.

29. Spot and Arc Welding

A good deal of progress is being made in America in the use of spot welding for the joining of thick plates. It is believed that spot welding has a great future as applied to shipbuilding and several large spot welders have been built for shipyards.

In some of its applications, spot welding affords a method of preliminarily joining the hull plates, after which the required additional strength is provided by arc welding. The Welding Research Sub-Committee has already made some progress in comparing combined spot and arc welds and combined rivet and arc welds with riveted, spot-welded, and arc-welded joints.

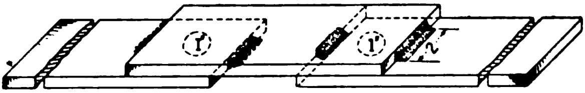

Fig. 9—Fillet and Spot Welded

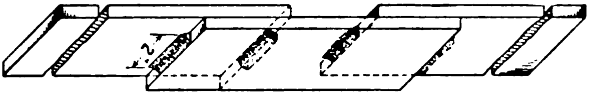

Fig. 10—Fillet Welded

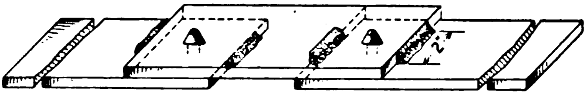

Fig. 11—Riveted and Fillet Welded

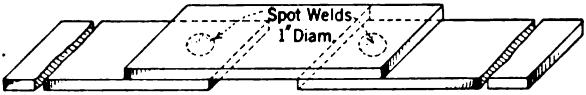

Fig. 12—Spot Welded

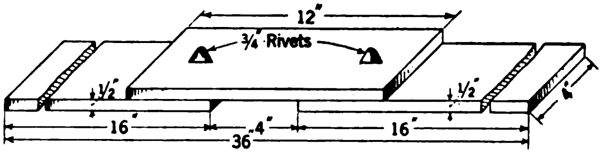

Fig. 13—Riveted Joint

It is not a question in such an investigation of spot *versus* arc welding, but of spot *and* arc welding.

In the tests mentioned, the specimens were made up of the following combination:

1. Spot and fillet welded Fig. 9 (2 samples made).
2. Fillet welded—made by welding fillets about two inches in length at the ends of the plates Fig. 10 (2 samples made).
3. Riveted and fillet welded Fig. 11 (1 sample made.)

4. Spot welded—made by welding two spots approximately one inch in diameter, on the plates Fig. 12 (2 samples made).

5. Riveted joint, made by riveting a ½-inch by 4-inch by 12-inch plate with two plates ½-inch by 4-inch by 16-inch, using two ¾-inch rivets and a 4-inch lap. (One sample made).

The results of the test show the comparative strength of the joints as follows:

Spot and fillet welded—	ultimate	load . . .	*50,350 lb.
Fillet welded—	"	" . . .	*37,000 "
Riveted and fillet welded—	"	" . . .	†35,000 "
Spot welded—	"	"	*28,000 "
Riveted Joint—	"	" . . .	†13,000 "

Spot welds, as compared with arc-welded butt joints, have the disadvantage of the increased weight corresponding to the overlap.

30. CONDITION OF SURFACES TO BE WELDED

While for spot welding the surfaces may sometimes be *too* clean to obtain the best weld, this cannot be the case with fusion welding. The question of the extent to which it is practicable to go in freeing the surfaces from impurities prior to making the fusion weld is entirely a commercial one. The cleaner the surface, the better the weld. In spot welding it is desirable to have clean surfaces under the electrodes, but scale *between* the two plates is a positive advantage.

31. PRE-HEATING AND HEAT TREATMENT AND HAMMERING WHILE COOLING

Pre-heating, heat treatment and hammering, as applied to fusion welding (both gas and electric) have been the subjects of research, but as yet nothing adequately comprehensive has been planned. It is very important that these deficiencies should be recognized and remedied.

32. TIME REQUIRED TO TRAIN WELDERS

As to the training of welders, there are on the one hand those who are so ill-informed as to assert that good welding can be done after a very few weeks of training, while on the other hand, others assert that an operator can hardly acquire any considerable degree of skill in much less than a year. Still others advocate the substitution of automatic feeds and the complete elimination of dependence upon manual dexterity. For arc welding work requiring more than 100 amperes this is, in the author's opinion, not a trade for women when the arc is manipulated by hand as distinguished from the use of automatic or semi-automatic machinery.

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*Average of tests on two samples.

†Only one sample made.

33. QUESTION OF NEED FOR SPECIAL MACHINES FOR WELDING

A great variety of machinery for supplying and controlling the current for welding is on the market. Some of this machinery comprises elaborate mechanisms in virtue of which it is claimed that it would be very difficult for even a novice to make a bad weld. Some advocate the use of simple resistance to be inserted in series with the arc on any available circuit, and claim that any additional machinery is superfluous. The capital outlay for the equipment of a welder (at the point of consumption) when the first kind of equipment is used, may be a matter of over $1000.00, while in the second case, well below half of that sum is sufficient.

34. TECHNIQUE OF TESTING WELDS

The ideal weld should presumably be at least as strong and as durable as the metal of the members joined together. In other words, the section containing the weld should have the same chemical and physical characteristics as adjacent sections in the original metal. A weld is therefore measured by the degree of approximation to this condition as dertermined by mechanical, chemical and metallurgical tests of:

a. The parent metal
b. The welded joint
c. The deposited material in the weld.

While during the last year the Welding Research Sub-Committee has made a great deal of progress in establishing standard procedures for the mechanical testing of welds, much still remains to be done. Obviously, the procedure for testing the original metal should follow standard practise as recommended by the American Society for Testing Materials, but there is considerable difference of opinion and uncertainty as to just how and what mechanical tests should be made of the welded joint and of the deposited metal. For instance

a. Should all the usual observations be taken when making a tensile test of a welded joint? Obviously the strength of the

metal should be determined
ty of the specimen, does not
h to yield point, elongation
series of welds having the
original metal is concerned,
ant for comparison purposes
of the original metal, ques-
as to just what extent these

ormation as to the ductility
ation and reduction of area
ecimens prepared from the
s cut lengthwise of the weld

test, which is a test for
ling the author) who would
f the mandrel *normal* to the
ich latter position is the one
t both tests should be made;
e ductility of the deposited
as an additional test of the
rial and the original metal.
tests and impact or shock

ts are generally conceded to
taining reliable information
de probably transcends (at
any other research in the
rches should be made:
igue machine
high speed, as employed by

n-fatigue machine
ding fatigue apparatus

rk has been done to solve
pertaining to the testing of
he testing procedure can be
balanced between the cost of
f testing necessary to insure

CONCLUSION

The extent of the field of application for fusion welding and spot welding is but little appreciated by engineers other than those who have been directly connected with welding developments. It is evident that this field is an enormous one, including as it does all structures where steel is employed, such as bridges, building structures, tanks of all types and kinds, railway rolling stock, and ships, in addition to numberless miscellaneous applications in industry in general.

However, engineers associated with welding research should be on their guard that their enthusiasm over this great field of application shall not lead them into prematurely endorsing the use of fusion welding or spot welding in constructions where the consequences of failure involve serious menace to life and property, as may often be the case. For example, a particularly important case is that of pressure vessels and especially large high-pressure containers. The success in one hundred installations will not excuse failure (accompanied possibly by fatalities), in the one hundred and first installation. It is the opinion amongst the best informed engineers that before fusion welding can advisedly be employed for large high-pressure vessels, much vigorous and elaborate research work should be carried out on the fatigue characteristics of fusion welds of long seams, and that this research work must comprise full-sized structures since the conditions cannot be reproduced in test samples.

In fact, if the general acceptance of welding, particularly by Inspection boards, underwriters, and classification societies, is to be accomplished in a reasonably short time, such extensive research work on a large scale is absolutely essential in order to demonstrate conclusively that welded joints are equal to or better than joints made by other methods. Obviously the development of the art could proceed along the lines of the usual order of evolution as in the cases of previous arts, but this would, as in those cases, involve the lapse of years.

For structures subjected to less extreme stresses, such as the hulls of ships, the adequacy of fusion welding as a substitute for riveting is in process of being thoroughly demonstrated in actual practise in Great Britain. It is recognized that the hulls of ocean-going ships are exposed to very great stresses, nevertheless there is a clear distinction between the magnitude of

:resses to which many large, high-
ɔjected.

paper will aid in focusing attention
of the welding art, particularly by
ıe many problems in welding research
mentioned in the paper.

ɜrtake to give adequate acknowledg-
o his many associates in the prepara-
most generous assistance has been
Mr. William Spraragen has extended
:ing data and in many useful ways.
: engineer of the Electrical Testing
ɜry generously of his time in advising
ut many points which arose in the
of this paper.

pany this paper:

d Procedure for Testing Welding

:t-Jones Tests of Arc Welded Half-

Tests of Gas Welds.

ded Steel Box.

.ppendix A

'OR TESTING WELDING ELECTRODES.
EMERGENCY FLEET CORPORATION
VEMBER, 1918

pose of this specification is to provide
'or testing welding electrodes for
are submitted for the information
:he approval by, the Welding Com-
Fleet Corporation.

n describes a test *of electrodes* and
ɜlectrode and of an apparatus. The
s given the option of selecting the
t is made, does not make it a test of
ıan the employment of a particular
: said to make it a test of a welding
ɜd in making these tests may or may
:ance. It is sought to minimize the
lity of the operator by requiring the
ɜ by at least two operators.

The Welding Committee has two other Sub-Committees into whose province falls the approving and certifying of operators and approving and certifying of systems. The admission that these three tasks overlap does not involve any reason for delaying the important task of proceeding at once with the standardizing of the testing *of electrodes*.

2. *General Conditions*. a. Each applicant shall provide at his factory or elsewhere as he may elect, the necessary facilities and at least two operators for making the test welds prescribed by these specifications. Except when otherwise indicated in these specifications, the applicant shall select the apparatus and other conditions for making test welds which he considers most suitable for his electrodes.

b. The test welds shall be made in the presence of an *authorized representative* of the Welding Committee of the Emergency Fleet Corporation who will be empowered to certify as to the compliance with the conditions prescribed in the specifications. Also representatives of Lloyd's Register of Shipping and the American Bureau of Shipping shall have the opportunity to witness the making of the test welds.

c. Until otherwise declared, the *authorized representative* of the Welding Committee shall be the Electrical Testing Laboratories, 80th Street and East End Avenue, New York, N. Y.

d. The Welding Committee shall assume charge of the completed test welds and have them tested by the *authorized representative* in accordance with these specifications.

e. The *authorized representative* shall render to the Welding Committee a complete, detailed report of each test of an electrode.

f. The cost of carrying out the prescribed tests shall be borne by the applicant.

3. *Sample Electrodes*. About 100 pounds of each electrode to be tested, which will be known as the *sample*, shall be furnished without charge. It shall be accompanied by an affidavit giving the following information:

a. The *trade name* under which the electrode is marketed together with certification that all electrodes bearing this trade name will be substantially the same as the sample submitted.

b. The manufacturer of the complete electrode.

c. The location of the factory in which the electrode was made.

d. The manufacturer of the welding wire.

e. The location of the mill in which the welding wire was produced.

f. The chemical analysis of the welding wire.

The *authorized representative* shall retain the remainder of the sample for reference purposes.

4. *Plate Material.* For these tests one-half inch ship plate shall be used. This material shall comply with the "*standard specification for structural steel for ships*" as adopted by the American Society for Testing Materials, serial designation A 12–16 (see page 98, A. S. T. M. Standards, 1918).

An abstract of this specification is as follows:

1. Open hearth steel.

2. Phosphorous $\begin{cases}\text{acid steel, not over 0.06 per cent.}\\ \text{basic steel, not over 0.04 per cent.}\end{cases}$

Sulphur, not over 0.05 per cent.

5. Tensile strength, pounds per square inch, 58000–68000

Yield point, minimum pounds per square inch, 0.5 tensile strength.

Elongation in 8 inches, minimum per cent., $\dfrac{1{,}500{,}000}{\text{tensile strength}}$

6. Yield point by drop of beam method.

7. Cold bend test; no cracking on outside of bent portion when bent 180 degrees around a pin the diameter of which is equal to the thickness of the plate.

5. *Cutting of Plates.* a. The method of cutting a plate 5 feet by 20 feet into pieces for welding is shown in the accompanying reproduction of drawing No. 102 of the Bureau of Standards.

b. Each plate shall be given a distinguishing letter, A. B. etc. This letter shall appear upon each piece cut from it.

c. Pieces shall be plainly marked with the letter and number arranged as shown in the drawing so that the location of the piece in the plate may be determined.

d. The plates from which tensile, cold bend and fatigue specimens are to be made, shall be cut into pieces 9 inches by 30 inches (see Fig. 14.)

e. The plates from which impact specimens are to be made shall be cut into pieces 30 inches by 30 inches (see Fig. 17).

Notes.—A power shear may be employed for cutting these plates if they are left flat. Pieces whose dimensions are within ¼ inch of the required size will be satisfactory.

6. *Arrangement of Piece for Welding.* a. All welds are to be made across the grain, that is, the welded joint is to be at right angles to the direction of rolling. Fig. 15 shows the correct arrangement of the pieces for the test welds to be used for the physical tests, but in Fig. 17, which shows the arrangement of pieces for the impact test, pieces such as J–1 and J–2 should be taken for a test weld instead of J–1 and J–9.

FIG. 14

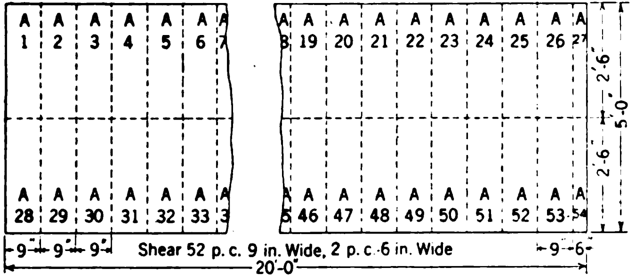


FIG. 15

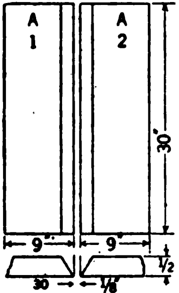


FIG. 16

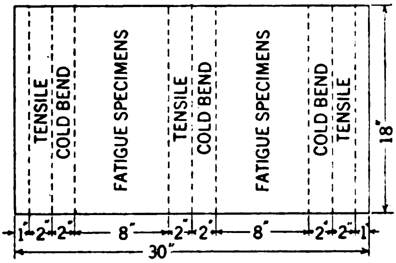
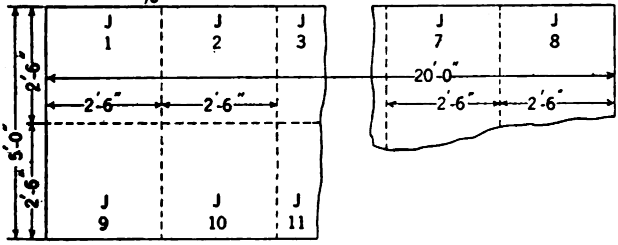


FIG. 17



Specimens for Tests of Welding Electrodes. Welding Research Sub-committee Emergency Fleet Corp. Bureau of Standards, Wash., D. C.

No. 102—VII-I Nov. 9, 1918

Changed Nov. 25, 1918

b. Preparatory to making a weld, one 30-inch edge of each piece will be beveled at the angle preferred by the applicant.

If he has no preference, the angle of the bevel shall be 30 degrees as shown in Fig. 15. The bevel is not to be carried through to the bottom edge but only to within 1/16 inch of the bottom edge. In other words, the ends of the pieces to be welded are not to be beveled to a sharp point but 1/16 inch of the original square edge will be left at the bottom of the Vee.

c. For welding, the pieces shall be placed horizontally with their under surfaces raised approximately ⅛ inch above the supporting surface. The beveled edges shall be placed parallel and separated ⅛ inch.

d. The weld shall in all cases be of the type known as a double bevel.

7. *Welding of Pieces.* a. The pieces, which shall be dry and free from rust and foreign substance, shall be "tacked" at each end and in the middle of the joint by welding the plates at each of these places for about one-half inch.

b. After "tacking" the weld shall be completed by working continuously from one end of the joint to the other. The welding material shall be added in at least two layers and when completed the surface of the weld shall be at least flush with and not more than ⅛ inch above the upper surface of the plate. The width of the weld at the top shall not be greater than 1¼ inches. All welding shall be done from the open side of the Vee.

c. After each layer of a weld is completed, it shall be inspected by the *authorized representative.* If unsatisfactory, a new test weld shall be substituted and a report made of reasons for rejection.

8. *Number of Test Welds.* a. The welds will be made by three skilled operators, two of whom will be furnished by the applicant and one by the Welding Committee.

b. Each operator shall make one 30-inch weld for the tensile, cold bend and fatigue tests (see Figure 15) using direct current and a similar weld using alternating current. For these tests, therefore, six (6) test welds will be required for each sample electrode.

c. Each operator shall also make one 30-inch test weld for the impact test (see Fig. 17) using direct current and a similar weld using alternating current. For impact tests, therefore, six (6) test welds will be required for each sample electrode.

d. If, however, the applicant intends his electrode for use with only one kind of current, that kind only shall be used in making the welds. In that case only three (3) test welds will be reauired for (b) and for (c) instead of six (6).

9. *Arrangement of Conductors.* a. One of the conductors shall be attached to a clamp which will be fastened to both pieces at the end of the joint opposite that from which work is started.

b. For direct current work, the electrode shall have the polarity desired by the applicant. In the absence of any preference on his part, the instructions of the *authorized representative* shall be followed.

10. *Welding Data.* The following information and observations shall be reported by the *authorized representative* during the welding operations.

a. Trade name or other identification mark of the electrodes.

b. Complete description of the electrode.

c. Sufficient description to identify the welding apparatus or system employed.

d. Identification marks on the pieces being welded.

e. Name of operator.

f Kind of current (*i. e.*, direct current or alternating current); if direct current, polarity and if alternating current, frequency.

g. Electrical quantities as follows: arc volts (both open and closed circuit), arc current and arc watts.

h. Room temperature and humidity.

i. The opinion of the *authorized representative* of the working quality of the electrode. This statement to include a description of any sputtering, boiling or other noticeable peculiarities.

j Elapsed time per weld.

k. Weight of electrode consumed per weld.

l. Any other information which will assist in determining the performance of the electrode, such as a photograph of at least one weld, etc.

11. *Preparation of Welded Plate and of Specimens for Physical Tests* (see Fig. 16).

a. Each test weld shall be machined down on both sides to about the surface of the plate.

b. Specimens shall be cut from *each* test weld reserved for physical tests as follows:

1. *Three Tensile Specimens.* These shall be machined to a uniform width of 1.5 inches unless a weld of great

strength makes it necessary to leave shoulders at the ends, in which case the standard A. S. T. M. test specimens for sheet iron and steel shall be prepared.

2. *Three Cold Bend Specimens.* These shall be machined to a uniform width of 1.5 inches.

3. *Six Fatigue Specimens.*—These shall be machined to about ½ inch diameter and 10 inches long. (The exact dimensions are to be determined by experiment.)

12. *Physical Tests.* a. *Tensile Strength.* Each of the three specimens shall be tested in accordance with the practise recommended by the A. S. T. M. and shall include the determination of the tensile strength, yield point (by drop-of-beam), method), reduction of area and total elongation after rupture in two inches and in eight inches.

b. *Cold-bend Test.* This test shall be made by placing the specimen on two rollers with the apex of the Vee upward and midway between the rollers and loaded at the center of the span thus formed by a cylindrical surface having a diameter of one-half inch. This surface shall bend the specimen downward between the rollers until a fracture appears on the lower side of the specimen when loading shall be stopped and the angle noted through which the specimen has been bent.

c. *Fatigue Test.* Each of the six specimens shall be tested in a special rotating type of machine similar to that used by Lloyd's Register of shipping. (Exact details to be determined by experiment.)

d. *Impact Test.* Each impact-test specimen shall be placed on supports 18 inches high and 4½ feet apart. A spherical weight of 500 pounds shall be allowed to fall freely through a distance of 10 feet striking the weld which shall be at the center of the span. The apex of the Vee shall be upward.

e. *Test of Original Plate.* In order to establish the physical properties of the unwelded plate, tensile, cold-bend and fatigue tests shall be made on a sample selected at random from the pieces used for the test welds but before such welds are made.

OPTIONAL TESTS

The following tests are optional with the applicant but the welding Committee considers that they give information of great importance and recommends that they be made in order to make the report on the electrode more complete.

13. *Chemical Analysis.* A chemical analysis shall be made of:

a. The original plate in one test weld selected at random.

b. The metal at the center of one test weld selected at random. If test welds are made with both direct current and alternating current, an analysis shall be made of one weld of each set.

14. *Photomicrographs.* Photomicrographs shall be made of one specimen weld selected at random as follows: (If test welds are made with both direct current and alternating current, photomicrographs shall be made of one weld of each set.)

a. At center of weld.
b. At juncture of weld and original metal.
c. In adjacent original metal.
d. Cross section of electrode.
e. Longitudinal section of electrode.

Appendix B

WIRT-JONES TESTS OF ARC-WELDED HALF-INCH SHIP PLATE

In Tables IV and V are set forth the results of the tests carried out in 1918 on arc-welded half-inch ship plate by the Welding Research Sub-Committee. The plates with which the welds were made had their edges prepared with a 45-degree double-Vee. The welds were made by a dozen different concerns. In each instance the operator employed whatever conditions were considered most suitable. Several types and sizes of electrodes, including both bare and covered, were used. While in the majority of cases direct current was employed, alternating currents of 25 and 60 cycles are also represented in the series. The number of layers and the current employed and, indeed, all the conditions, were left to the discretion of the individual operator. The length of the weld was eight inches. After the welds were made, the plates were cut up and tests were made at the Bureau of Standards under the direction of Prof. H. L. Whittemore. The tensile tests were made on specimens with a cross-section of one in. by one-half in. Specimens with the weld machined have the projecting metal planed off so that the welded portion is smooth and of approximately the same cross-section as the remainder of the specimen. For the specimens with the weld not machined, no record was made of the added cross-section due to the projecting material.

The cold bend specimens were one in. by one-half in. and were bent around a mandrel of 1.5 in. diameter. The results

TABLE IV
WIRT-JONES TESTS OF ONE-HALF-INCH ARC-WELDED SHIP PLATES

(Machined Samples)

Test number	Current in amperes		Diam. of elec. in in.	Current density, amp. per sq. in.	Tensile tests		Bending	Electrode		
	a-c.	d-c.			Ult. lb. per sq. in.	Per Cent. Elon. in 2 in.	Angle at which crack starts, degrees	Cov.	Bare	Make
20	175	...	0.125	14,227	62,700	9.0	34	C	..	E.A.C.& W.Co.
1	...	175	0.166	9,118	59,800	9.0	42	..	B	Roebling
22	160	...	0.125	13,008	50,000	6.0	78	C	..	E.A.C.& W.Co.
2	...	155	0.156	8,075	62,600	11.5	44	..	B	Roebling
19	150	...	0.125	12,195	62,800	12.0	32	C	..	Quasi
31	...	150	0.166	6,930	60,900	8.0	..	..	B	Roebling
29	...	150	0 156	7,815	56,400	6.5	..	..	B	W.W.& M.Co.
38	150	...	0.156	7,815	54,500	7.0	45	C	..	E.A.C.& W.Co.
29	...	150	0.156	7,815	54,400	6.0	47	..	B	W.W.& M.Co.
9	...	150	0.156	7,815	44,200	4.0	26	..	B	Toncan
9A	150	...	0.187	5,430	42,500	4.0	30	..	B	Armco
10	...	150	0.156	7,815	41,900	4.5	25	..	B	Toncan
10	...	150	0.156	7,815	41,300	4.5	24	..	B	Toncan
9	...	150	0.156	7,815	38,100	4.0	15	..	B	Toncan
9A	150	...	0.187	5,430	36,300	4.0	..	..	B	Armco
5	...	145	0.156	7,554	61,100	8.5	55	..	B	Am.S.& W.Co.
25	136	...	0.156	7,085	43,700	3.5	26	..	B	Roebling
30	...	135	0.156	7,033	53,200	11.0	..	..	B	W.W.& M.Co.
30	...	135	0.156	7,033	52,000	10.5	50		B	W.W.& M.Co.
37	125	...	0.125	10,162	56,400	7.0	42	C	..	E.A.C.& W.Co.
7	...	120	0.125	9,756	57,600	8.5	50	..	B	Roebling
7	...	120	0.125	9,756	53,700	7.0	45	..	B	Roebling
8	...	115	0.125	9,349	59,400	13.5	60	..	B	Roebling
8	...	115	0.125	9,349	58,200	14.0	..	..	B	Roebling
3	...	115	0.156	5,891	50,600	5.0	34	..	B	Am.S.& W.Co.
16	...	110	0.134	7,799	50,250	7.0	35	C	..	Quasi
27	...	110	0.125	8,943	45,800	8.0	42	..	B	Roebling
21	105	...	0.134	7,444	42,200	5.0	42	C	..	E.A.C.& W.Co.
26	94	...	0.125	7,642	34,200	3.0	15	..	B	Roebling
18	90	...	0.134	6,381	54,000	6.0	65	C	..	Quasi
15	...	90	0.134	6,381	39,400	4.0	30	C	..	Quasi
24		86	0.125	7,154	45,400	6.0	15	..	B	Roebling
23	...	85	0.125	6,930	51,900	4.0	..	..	B	Roebling

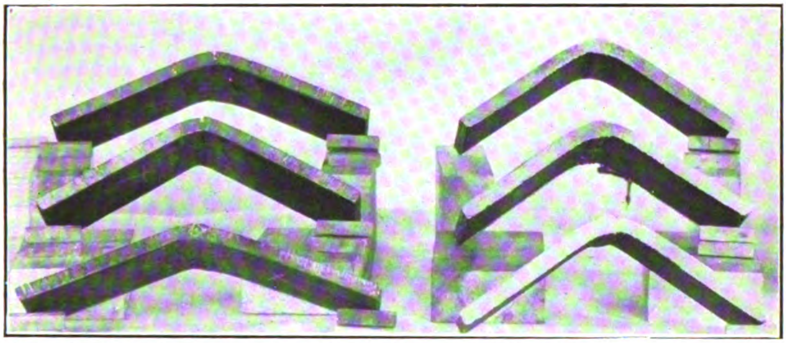


FIG. 8—GAS AND ELECTRIC BENT SAMPLES (GAS WELDS AT LEFT AND ELECTRIC WELDS AT RIGHT)

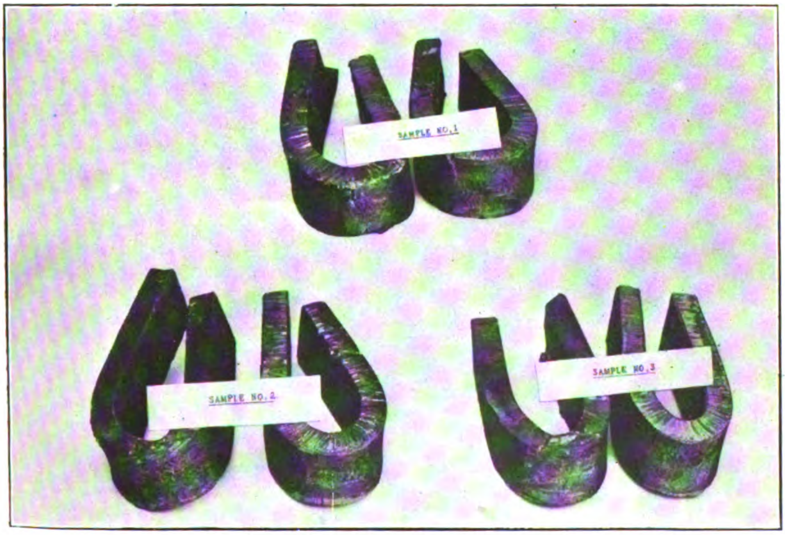


FIG. 18 [HOBART]

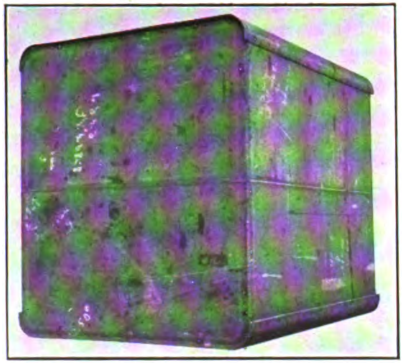
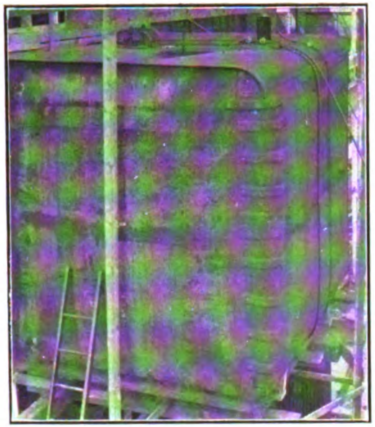
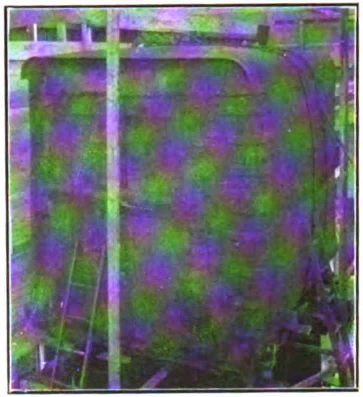


FIG. 20—ELECTRIC-ARC WELDED STEEL BOX OF ONE-HALF INCH TANK STEEL



FIG, 21—ELECTRIC-ARC WELDED BOX UNDER 22-INCH VACUUM—SHOWING TOP SIDE DEPRESSED



[HOBART]

FIG. 22—ELECTRIC-ARC WELDED STEEL BOX UNDER 15 LB. HYDROSTATIC PRESSURE—ONE PHASE OF THE BREATHING TEST

of the tensile and bending tests for the machined samples are given in Table IV. Those for the samples which were not machined are given in Table V.

TABLE V.—WIRT JONES TESTS OF ONE-HALF INCH ARC-WELDED SHIP PLATES

(Samples Not Machined)

Test No.	Current in amperes		Diam. of elec. in inches	Current density, amp. per sq. in.	Tensile tests		Electrode		
	A. C.	D. C.			Ult. lb. per sq. in.	Per cent elon. in 2 in.	Cov.	Bare	Make of Electrode
20	175	...	0.125	14,275	66,480	11.0	C	..	E.A.C.&W.Co.
22	160	...	0.125	13,008	66,400	9.0	C	..	E.A.C.&W.Co.
19	150	...	0.125	12,195	65,400	6.0	C	..	Quasi
5	...	145	0.156	7,554	52, 280	7.0	..	B	Am.S.&W.Co.
25	136	...	0.156	7,085	47,800	4.0	..	B	Roebling
3	...	115	0.156	5,891	65,470	13.0	..	B	Roebling
27	...	110	0.125	8,943	48,200	7.0	..	B	Am.S.&W.Co.
16	...	90	0.134	6,381	58,740	5.2	C	..	Quasi
18	90	...	0.134	6,381	61,760	11.0	C	..	Quasi
15	..	90	0.134	6,381	57,340	8.0	C	..	Quasi
23	...	85	0.125	6,910	57,060	5.0	..	B	Roebling

Appendix C

BENDING TESTS OF GAS WELDS

Too late for inclusion in the body of this paper there has been brought to the author's attention some gas welds made under the direction of Mr. H. I. Walsh, which have withstood very severe bending tests before failing. The specimens are shown in the illustration Fig. 18. Three pairs of specimens welded with three kinds of electrodes are shown. These specimens show much greater ductility than those shown in Fig. 8.

Appendix D

ARC-WELDED STEEL BOX

Mr. R. E. Wagner has prepared the following description of a large steel box, arc welded with bare electrodes at Pittsfield. The box was built and tested in the latter half of 1918. It was made of half-inch-thick tank steel and its dimensions were 12 ft. by 10 ft. by 9 ft. The total weight was 16,000 lb. The welding was done with 75-volt direct current. This box contained eleven different varieties of welds. Its general dimensions and the types of welds used are shown in Fig. 19. No rivets were used in its construction.

The principal objects to be ascertained in the construction of this box were:

1. Could a structure of this character be made close to drawing dimensions and without excessive distortions and warping of plates and parts?

2. Would the structure be strong and capable of withstanding severe shocks and distortions without serious ruptures?

3. What are the detail costs and time required to build such a structure?

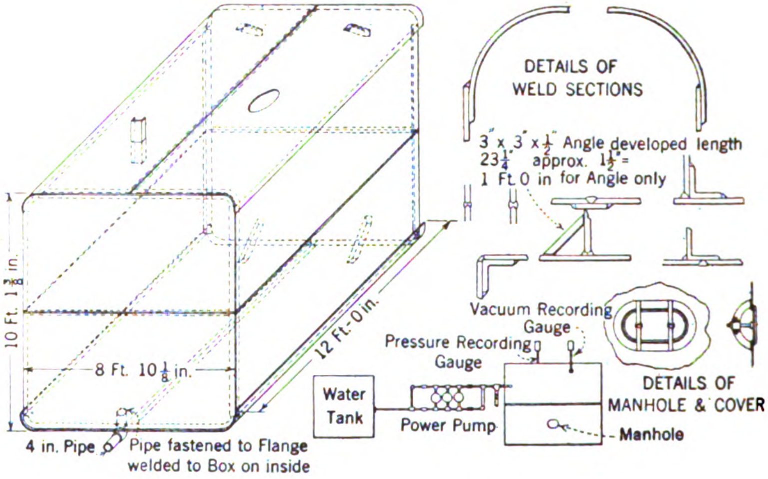


Fig. 19—Outline and Dimensions of Arc-Welded Steel Box

It was found that if proper allowances are made for contraction and expansion, especially where plates are butted and welded, the resulting plate will show very little warping. The maximum variation of the sides from a plane was 1.5 in. The general appearance of the box when completed is shown in Fig. 20.

The box, when finished, was strong and well built. All joints had a smooth workmanlike finish. A number of incipient leaks developed when the box was first filled with water, but these were closed by hammering. The box was subjected to a hydrostatic pressure test of 43 lb. per square inch, and, after it had been severely stressed and distorted, it ruptured at a corner, the break starting at the top and opening the entire corner. This corner was afterward repaired (as shown in Fig. 21), and the box was subjected to a "breathing" test consisting of alternate applications of 15 lb. pressure and 22 in. of vacuum.

During each cycle of this "breathing" test, the top of the tank had a maximum movement of 8 in. from bulge to depression. At the sides the movement was 6 in. Every time that the side, bottom and top plates moved from bulge to depression, there was a sharp snap of the plates as they moved from "arch in" to "arch out." These sudden changes in form subjected the welded joints not only to bending stresses but to severe snapping stresses. At the end of the twelfth cycle a break occurred in a double-bevel weld. At one end the break left the weld and went into the solid plate. This break was patched and the "breathing" tests were resumed. The next break which occurred after the 235th cycle of operation extended 24 in. into the solid end plate as well as 17 in. along a weld. This break will be repaired and the tests will be resumed.

The following cost data is of interest:

Welding	$ 151.00
Fabricating and assembling	134.00
Blacksmithing	24.00
Testing and supervision	50.00
Welding wire	30.00
Steel plate	651.00
Total cost	$1040.00

Total pounds of wire used	334
Total pounds of wire deposited and lost	299
Total scrap ends of wire	35
Total feet of welding	501
Total hours of welding	165
Total kilowatt hours	1011
Per cent scrap ends of wire	11
Wire deposited per foot (pounds)	0.6
Kilowatt hours per pound of wire deposited	3.4
Average feet welded per hour	3.0
Average kilowatt hours per foot of welding	2.0
Per cent. of time welder is welding	60
Diameter of welding wire, inch	3/16

Six different welders obtained the results noted, which are representative for a job of this character.

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PRESENT STATUS OF INDUSTRIAL LIGHTING CODES

BY G. H. STICKNEY

Abstract of Paper

In order to protect workers from accident and eye-strain, industrial lighting codes have been adopted in four states and in Federal establishments. Similar action is under consideration in several other states and there is prospect of extension throughout the country.

Investigation and experience indicate the need of government regulation of factory lighting. When adopted by industrial commissions under authority granted by Legislatures, the codes become in effect state law. Variations in the codes as adopted are less than might appear, some features being experimental. The existing codes correspond in essentials to the Illuminating Engineering Society code, on which they are based.

Mandatory regulations are necessarily limited in function to the assuring of safety. Higher standards are essential for efficient production. Popular education in which electrical and illuminating engineers can cooperate, is an important feature of future development.

Introduction

THE industrial lighting codes are an expression of the "Safety First" movement in terms of legal regulations directed to the lighting of factories. The prime function of these codes is the safeguarding of life, limb and vision of industrial workers. No argument should be necessary to enlist the support of all good citizens to such a humanitarian effort. In addition, the codes seem likely to teach practise which will enhance the earning power, not only of the workers themselves but also of the industrial plants. This incidental result seems likely to be of great economic importance in the coming period of international competition. Sufficient progress has been made to indicate that such regulations will ultimately be in force throughout the country. Through their relation to lighting practise, these codes seem destined to have a broad influence on electrical engineering, and it is the purpose of this paper to inform electrical engineers regarding the scope and tendencies of these codes, as interpreted from a close association with the work and with those responsible for it.

Industrial lighting codes, based on the Illuminating Engineering Society's code, are now in force in the states of Pennsylvania, New Jersey, New York and Wisconsin. In several other states similar codes have been drawn up and are under consideration for adoption. In others, bills looking to the adoption of the code have been introduced before the legislatures. As a war measure, the Advisory Commission of the Council of National Defense, through its Committee on Labor, appointed a sub-committee known as the Divisional Lighting Committee, to encourage the movement. The sub-committee, working through state representatives, has approached the authorities in each of the states to encourage the adoption of such codes. As the result of this activity, progress has been made toward the introduction of an industrial lighting code or a safety code, by the Department of Labor, Industrial Accident Commission, or other agencies charged with the enactment and enforcement or regulations in regard to factory lighting.

Through cooperation of the Bureau of Standards and the Federal Inspectors of Safety, a lighting safety code was adopted during the war, in all Federal establishments, including arsenals, munition plants and navy yards.

NECESSITY

The necessity for such regulation is well explained in the introduction to the new edition of the Wisconsin code, which reads as follows:

> Insufficient and improperly applied illumination is a prolific cause of industrial accidents. In the past few years numerous investigators, studying the cause of accidents, have found that the accident rate in plants with poor lighting is higher than similar plants which are well illuminated. Factories which have installed approved lighting have experienced reductions in their accidents which are very gratifying.
>
> Of even greater importance, poor lighting impairs vision. Because diminution of eyesight from this cause is gradual, it may take the individual years to become aware of it. This makes it all the more important to guard against the insidious effects of dim illumination, of glaring light sources shining in the eyes, of flickering light, of sharp shadows, of glare reflected from polished parts of the work. To conserve the eyesight of the working class is a distinct economic gain to the state, but regardless of that, humanitarian considerations demand it.
>
> Finally, inadequate illumination decreases the production of the industries of the state, and to that extent, the wealth of its people. Factory

managers, who have installed improved illumination, are unanimous in the conviction that better lighting increases production and decreases spoilage.

Illuminating engineers have recognized for a long time that inadequate lighting was responsible, in a greater or less degree, for industrial accidents, and that good lighting was a potent means of accident prevention. Extensive data, accumulated by John Calder[1], R. E. Simpson[2], and others provide convincing proof of this condition.

The loss of visual power, through improper lighting, cannot be so readily recorded, and hence is not so directly substantiated by actual data. It is, however, recognized as a serious menace by oculists[3] and others. Because it incapacitates the skilled worker just when he should be most valuable, and further, because the danger is not readily recognized by those immediately responsible for industrial lighting, the necessity for governmental supervision is even greater for this purpose than for the prevention of mechanical accidents.

In spite of the recent general improvement in industrial lighting practise, the increasing need of ample assurance in this matter is evident from the present tendencies of manufacturing, among which may be mentioned the following: the grouping of larger number of employees; the extension of all night processes; increasing use of dangerous machinery; intricacy of processes and specialization of workers requiring sustained visual application.

HISTORICAL

Practically all the codes in force or under preparation are based on the "Code of Lighting Factories, Mills and other Work Places" of the Illuminating Engineering Society[4], and conform closely to it in all essentials.

This code was prepared by the cooperative action of the Committee on Lighting Legislation, under the chairmanship of Mr. L. B. Marks, and the former Committee on Factory Lighting, under the chairmanship of Professor C. E. Clewell.

The Illuminating Engineering Society was called upon in 1913 to assist in formulating the lighting section of the labor law of New York State. It was found impracticable then to incorporate definite lighting specifications in the law, and so provision was made in the law for the later adoption of such regulations, by the Labor Commission. In preparation for the Commission's requirement, work of drafting a code was

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1. For references, see Bibliography.

undertaken. The problem proved a very difficult one and many modifications were found necessary, even after its first publication. Various societies, many engineers and state commissioners pointed out desirable changes, which were incorporated from time to time. Even at the present time, although the code is a very valuable working instrument, it is considered, by those who have had most to do with it, to be under development and liable to slight changes and amplifications, with the development of the art and with increased experience in application of the various provisions.

In 1916 at a meeting in Philadelphia[5], Dr. J. P. Jackson and Colonel L. T. Bryant, industrial commissioners of Pennsylvania and New Jersey, respectively, became interested, and after introducing some practical improvements, their respective commissions took action which resulted in the adoption of the code in the summer of 1916. The New York Commission adopted the code with some modifications and put it in force July 1st, 1918, some of the features being tentative for a year.

The Wisconsin Commission began issuing lighting orders in 1913, but these orders did not contain any specification as to intensity of illumination on the work. After thorough investigation the orders were superseded by the present code, which was issued in May 1918.

The author has just received word, as this paper goes to press, that the legislature of the State of Oregon has passed a bill establishing an industrial lighting code.

SCOPE

In the states which have adopted codes, the action has been by industrial or labor commissions, under the authority granted them by legislature, to promulgate rules in the interest of safety of industrial workers. The codes are, therefore, backed by the state police power.

Since the function of the Commissions is limited to insuring safety, the codes require only such lighting as is necessary for that end. Under these circumstances the codes cannot demand the higher standards of illumination desirable for economical production[6]. That the intensities specified are minimum limits, consistent with safety rather than good practise, is recognized, and in connection with all the codes, higher values representing more desirable practise are recommended.

It has seemed to be the experience of labor commissions that at least 90 per cent of the manufacturers cordially desire to comply with their regulations. The principal difficulty so far encountered in applying the codes, has been to make clear to the layman just what is required and how it can be secured. It has, therefore, been found expedient to publish educational sections supplementary to the codes proper. Such sections explain the principles involved and make suggestions for securing and maintaining good installations. The recent revision of the Wisconsin code treats rather comprehensively of the selection and location of lighting equipment, illustrated by charts.

By joint action of the Pennsylvania and New Jersey Commissions, a course of lectures[7] on the interpretation of the codes was given to their inspectors at the University of Pennsylvania in the spring of 1918. A similar lecture[8] was given to factory inspectors of the Board of Labor & Industries of Massachusetts in October 1918. Doubtless this will be repeated and the method applied elsewhere. The New Jersey Commission has held meetings of contractors and manufacturers, to assist in the educational work.

In all the codes, the employment of expert engineering or architectural advice is recommended.

SPECIFICATIONS

The principal lighting specifications common to all states which have adopted the code, are intensity, glare limits, and distribution. It is also usual to require provision of emergency lighting, watchman's circuits and certain switching provisions. In some cases these features are omitted from the codes, being provided for in the law or elsewhere.

A comparison of the codes adopted or under preparation shows a remarkable uniformity in the specification of these factors. There is some variation, especially as regards experimental features, but this is of a nature likely to help rather than retard the development of codes toward excellence and uniformity.

In drawing the specifications, it has been constantly recognized that they must be kept simple and practicable so that conformance could be determined without recourse to lighting experts or bulky and expensive instruments. On the other hand, it is desirable to make the specification as definite as possible, minimizing the part left to individual judgment and thus avoiding controversy and prejudice.

DAYLIGHT

While it has been considered desirable to require that new buildings and extensions be so constructed as to provide adequate daylight, it has been found very difficult, if not impracticable, to lay down a definite rule, and in most of the codes it has been assumed that the purpose was accomplished if suitable artificial light were required where and when daylight is unavailable.

Daylight is subject to a wide variation throughout the hours of the day, seasons of the year, with changes in weather and for different directions of window exposure, etc. In any building the natural lighting may be affected by surrounding construction on property not under the control of the owner. A workroom having ample daylight when erected may be darkened by later construction. In a dense manufacturing center, *e. g.*, downtown Manhattan, it would be impracticable to realize so good a condition, especially on lower floors, as might be reasonably required of a suburban factory. Some reasonable provision can undoubtedly be reached, which will at least require the minimization of glare and provide for wide distribution of light, by the use of suitable awnings, shades, refractive windows, etc.

The Wisconsin Commission has adopted the following rule in this connection:

> Order 2111. Natural Light. Windows, skylights, saw-tooth or other roof lighting construction of buildings shall be arranged with reasonably uniform bays and the glass area so apportioned that at the darkest part of any working space, when normal exterior daylight conditions obtain, (sky brightness of 1.5 candle-power per sq. inch) there will be available a minimum intensity equal to twice that of Order 2112 for artificial light.
>
> Awnings, window shades, diffusive or refractive window glass shall be used for the purpose of improving daylight conditions or for the avoidance of eye strain wherever the location of the work is such that the worker must face large window areas, through which excessively bright light may at times enter the building.
>
> Note. The intensity requirements for adequate daylighting are much higher than those for adequate night lighting, because in general, under daylight conditions, the light coming to the eye from all the surroundings in the field of vision is much brighter than at night, and hence a correspondingly more intense light must fall on the object viewed.

It is the almost universal experience of illuminating engineers and others, that it is possible to operate satisfactorily with a lower intensity of artificial than natural illumination.

The reason for this has not been satisfactorily explained; but with daylight the relatively high illumination of walls and other surrounding objects, compared to the illumination on the work, is undoubtedly a contributory cause.

In the earliest draft of the Illuminating Engineering Society's code, a ratio of 3 to 1 between natural and artificial lighting requirements was specified. Later this was changed to 2 to 1, and still later, in the absence of definite data in confirmation of the necessity of higher daylight intensities, artificial lighting was required when daylight intensities fell below the values specified for artificial lighting. The Wisconsin code and one or more of those under preparation, have adhered to the ratio of 2 to 1, which figure has also been used in the Illuminating Engineering Society's School Lighting Code. Further experience is apparently necessary before any final relation can be determined.

It is probable that in different conditions of daylight and of artificial light, the relative value varies. It is not likely, at least in the near future, that actual foot candle measurements will become the criterion for turning on the lighting, so that an accurate determination of this ratio does not seem to be of immediate importance.

The Illuminating Engineering Society, Pennsylvania, New Jersey and New York codes are essentially artificial lighting codes and do not attempt to specify daylighting. On the other hand, serious conditions of glare are not infrequent in the natural lighting of workrooms, and the extension of the code to mitigate such conditions seems to have considerable merit.

From a hygienic standpoint, sunlight has desirable features distinct from its relation to vision, so that it is desirable to have daylight available wherever possible.

There are some processes which inherently require the exclusion of daylight. Moreover, in the large cities workrooms, such as engine rooms, pipe shops, etc. have been established in basements, apparently without serious harm to the workers. On a larger scale, workrooms have been established above ground, which require artificial lighting throughout the day.

Unquestionably, all visual requirements can be provided with proper artificial lighting. It is, therefore, doubtful if a mandatory requirement of daylight for all places is justifiable. One of the codes under preparation, but not yet adopted, meets these conditions by simply specifying the lighting features necessary without distinction as to whether the light is natural or artificial.

INTENSITY SPECIFICATION

In all the codes which have come to the author's attention, intensity is specified in foot-candles. While at first some difficulty was anticipated in explaining these values and providing for their measurement, the development of an inexpensive and simple "foot-candle meter" has facilitated the application of these specifications.

For yards, passageways, aisles and stairways, the intensity on a horizontal plane, at or near the floor level, is assumed for measurement.

For various operations, the intensity is required at the work and would naturally be measured in the plane of any surface requiring vision of the character indicated. In all cases the limits are given as minima, not averages.

It has been generally recognized in selecting the intensity levels that there are no definite critical points, where a variation of a small percentage, one way or another, would cross a definite line between safety and danger. In determining the various intensity levels, lighting experts have drawn on their experience, supplemented by special investigation. It inspires confidence to note that the American values correspond rather closely to those determined independently in England after a very exhaustive investigation under governmental auspices[9].

The intensity specifications naturally fall into two groups: those required over general spaces and those required for work operations. The former are primarily for the prevention of accident, while the latter have the added element of conservation of vision, especially in the higher intensity classes.

A lower standard is allowed out-of-doors than indoors, on account of the difference in the usual character of surroundings and the nature of travel. The large out-of-door areas must, for economic reasons, have a low intensity requirement, and it would not be reasonable to demand much more than ordinary street lighting or moonlight intensities. The value of 0.02 foot-candle, therefore, appears in all the codes. For interior lighting a minimum of 0.25 foot-candle has been required for all traversed spaces.

New York and Wisconsin have included a classification to cover elevators, washrooms, dressing rooms, etc. at 0.5 foot-candle. This has not appeared in the earlier codes, but seems to be a useful addition.

The lowest intensity for manufacturing under the Illuminating Engineering Society, Pennsylvania, New Jersey and Wisconsin codes is 1.25 foot-candles. New York has adopted 1 foot-candle for the corresponding class, *i. e.*, rough manufacturing. While this value is, in the opinion of some engineers, lower than desirable, there is doubt if there is evidence to warrant the standardization of the fractional value.

The New York Committee has also adopted a new level of 0.5 foot-candle for the handling of materials and other very rough operations, and this step is being included in some of the codes in preparation in other states.

The higher steps are the same in all codes being located at 2.3 and 5 foot-candles, according to the fineness of vision required by the operations.

While it is true that there are operations requiring more than 5 foot-candles, they are exceptional and usually performed by highly skilled specialists. As such individuals are likely to be able to protect themselves, it has not seemed necessary for governmental authorities to take action.

Exceptions arising from the nature of a few processes are necessary to the illumination intensity requirements, as they appear in most of the codes. The omission has been due to the belief on the part of certain commissions that the exceptions were so infrequent and obvious that they can be taken care of readily and thus avoid misunderstanding on the part of others not entitled to exception.

One of the codes under preparation includes a class of zero intensity, while another lists the exceptions in a note following the intensity rule. This reads:

"Note: Some exceptions to the Intensity Rule:

a. There are some operations that are performed in comparative darkness, as for example, photographic processes in the dark room.

b. There are some operations that are best observed by their own light as in the parts of the process of working glass.

c. Some operations are best observed by the "silhouette" method of lighting in which the work is seen against a lighted background in a comparatively dark room, as in some processes of working with dark threads and lamp filaments.In all such cases in which work is of necessity carried on in comparative darkness, special precautions should be taken to properly safeguard the workmen.

A limiting feature of the intensity specification is the rather indefinite descriptive classification of the operations assigned to the various levels. The need of more definite descriptions is well known to all who have undertaken the work of drawing up specifications. It is sometimes important that an inspector or a manufacturer be able to tell without question within what class any particular operation falls. This, however, is not so serious as a superficial consideration might indicate, being somewhat ameliorated by the fact that manufacturing economy should dictate a much higher intensity than required by the codes.

Many efforts have been made to render the specifications more definite, but the problem is much more difficult than appears at first. There are many degrees of fineness in the same type of process as carried on in different shops or even in the same shop. Lathe work in machine shops, for example, varies in fineness all the way from very rough work down to watchmakers' fineness. An article is made by one manufacturer, say to 0.01 inch of accuracy, while another making nominally the same article works to 0.001 of an inch or finer.

Several proposals have been made, among which may be mentioned:

a. To make the intensity table simply an index of intensity levels, each indicated by an arbitrary designation (a, b, c, etc.) without any description of the process covered. Supplement this with a complete list of all manufacturing processes, using the symbol to designate the particular class to which each process is assigned.

b. To supplement the present classification with a detailed list of standardized processes.

The latter scheme (b) seems to have some advantages provided it is not extended too fast so as to lead to confusion through repeated changes. The New York Commission has adopted tentatively for a year, a list of this sort, but has found it necessary so far to use in many cases the qualifying terms "rough work", "medium work" "fine work", which make the specification in such cases but little more definite than the general classification.

The first plan (a) has some ardent advocates, but has been objected to on the ground that such a list implies an accuracy of description that does not really exist. Another objection is that the space occupied by such a list seemed likely to overemphasize the intensity specification as compared with other code specifications. It seems quite probable that this method will be tried out in one state, in which case its relative merit will be better determined by experience.

In general, it seems desirable for the ultimate good of all that most states adhere to the broad descriptive specification, while a few experiment with the extensions and determine their practicability. They will then be more readily able to adopt any method which shall have been found especially meritorious.

Glare Limit Specification

The establishment of proper limits for glare is probably more important than even the matter of intensity. While the provision of sufficient light is fundamental, it is also better understood and has a more obvious relation to production. It seems to be generally agreed that more employes suffer from glare than from insufficient light. Certain lighting conditions are readily recognized as glaring, while others are equally recognized as free from objectionable glare. But when it comes to drawing a definite limit between danger and safety, our present inability to measure or accurately define objectionable glare makes it necessary to utilize a qualitative rather than a quantitative specification.

The I. E. S. Pennsylvania and New Jersey codes simply require that lamps be "suitably shaded to minimize glare," with an explanatory note that glare from lamps or unduly bright surfaces produces eyestrain and increases accident hazard. This is supplemented by the requirement (under "Distribution of Light on Work") that "sharp contrasts of intensity" on the work be avoided.

The New York code requires that "exposed bare lamps, located less than 20 ft. above the floor, shall be provided with shades, reflectors, diffusing glassware or other accessories, to eliminate or minimize glare." Sharp contrasts of intensity on the work must also be avoided.

The Wisconsin Code goes a little farther and says,

> Lamps suspended at elevations above eye level less than one-quarter their distance from any position at which work is performed, must be shaded in such a manner that the intensity of the brightest square inch of visible light source shall not exceed seventy-five candle power.
>
> Exception: Lamps suspended at greater elevations than twenty feet above the floor, are not subject to this requirement.
>
> Note: (a) Glare from lamps or unduly bright surfaces produces eyestrain and increases the accident hazard.
>
> The brightness limit specified in this order is an absolute maximum. Very much lower brightness limits are necessary in many interiors illuminated by overhead lamps, if the illumination is to be satisfactory.

In some cases the maximum brightness should not exceed that of the sky (1.5 to 3.0 candlepower per square inch).

Note: (b) Where the principal work is done on polished surfaces, such as polished metal, celluloid, varnished wood, etc., it is desirable (but not mandatory at present) to limit the brightness of the lamps in all downward directions to the amount specified in this order.

For local lighting the Wisconsin code establishes the limit of 3 candle power per square inch, whenever visible from any working position. This lower limit is selected "because the eyes are more sensitive to strong light received from below."

There is a difference of opinion among illuminating engineers as to the proper values of candle power per square inch to be applied to this specification, while some think a better principle of specification can be determined. It has been suggested that glare be specified in terms of contrast of brightness, perhaps expressed in ratios. Some experimental work has been done along this line and at least two experimenters have made up experimental instruments for measuring ratios of brightness. It is recognized that there is a considerable range in the permissible contrast for different processes for different directions, especially of elevation, and for different intensities.[10]

It therefore seems likely that sometime in the future the codes will have some sort of glare classification corresponding to the intensity classification. But advance in such a direction cannot be made until further investigation and development has provided a reliable basis.

Considerable space has been devoted to the engineering limitations of the present glare specifications, with the view of interesting experimenters and engineers in the solution of the problem. On the other hand, the present specifications must not be regarded in any way as a failure. They are practical, working specifications which will do much to improve lighting conditions. They provide the means of eliminating practically all conditions which constitute a serious menace, and while the lack of a defined limit may in some cases be taken advantage of by either the manufacturers or the inspectors, such instances are likely to be quite exceptional. In reality the present specification is more definite than many existing legal requirements in force regarding matters other than engineering.

DISTRIBUTION OF LIGHT

The New Jersey code reads: "Lamps shall be installed in regard to height, spacing, reflectors or other accessories, so as to secure a good distribution of light on the work, avoiding objectionable shadows and sharp contrasts of intensity."

The distribution of light is partly taken care of in the intensity and glare limit specifications. That is, the requirement that intensity shall not fall below a certain minimum, coupled with economic considerations, tends to avoid a wide variation in intensity, while the latter also requires the elimination of dense shadows on the work. As worded in most codes these rules do not call for the elimination of bright striations of light, or, in brightly lighted rooms, of shadows which may interfere with vision but still have an intensity above the minimum limit.

The distribution of light rule covers these omissions, by calling attention to the relation of lamp equipment and location to light distribution. The lighting effects referred to, if objectionable, are so obvious that they are readily recognized when attention is called to them. Therefore, the rule seems likely to accomplish its purpose without much difficulty.

In the Wisconsin code a further requirement is made that the local lighting shall be supplemented by a moderate intensity of overhead lighting, except when reflection from light colored surfaces produces a general illumination. This renders more definite a feature than is implied by the general requirement of the rule.

EMERGENCY LIGHTING

Panics, which have occurred in crowded rooms when the lighting has failed at the time of a fire, explosion or other emergency, have emphasized the necessity of avoiding any probability of darkness at such a time. There is, however, a wide variation in the actual needs of different workrooms. For example, where a large number of women workers occupy an upper floor surrounded by dangerous conditions, inflammable materials, etc. continuity of lighting is exceedingly important. But where a small number of employes are scattered over a large ground floor area, with convenient exits and without dangerous conditions, safety can be assured without an elaborate provision for continuity of lighting. Moreover, such provision as would be necessary in the first instance, might be prohibitively expensive for the second.

It has, therefore, seemed necessary to make only a general provision in the code, with the expectation that rulings would be made to cover specific cases, or that the detailed requirements would be supplied later by those having suitable experience. It is more a problem of safety engineering than of illuminating engineering.

The general requirement of the rule, common to most of the codes is: "Emergency lamps shall be provided in all work space aisles, stairways, passageways and exits. Such lamps shall be so arranged as to insure their reliable operation when through accident or other cause the regular lighting is extinguished." In some states the rule has been expanded to include instructions for insuring reliable operation—separate mains or sources of energy being required.

For example, the New Jersey code requires—

> Emergency lighting systems, including all supply and branch lines, shall be entirely independent of the regular lighting system and shall be lighted concurrently with the regular lighting system and remain lighted throughout the period of the day during which artificial light is required or used.
>
> Emergency lighting systems shall be supplied from a source independent of the regular lighting system wherever possible. This source of supply and controlling equipment shall be such as to insure the reliable operation of the emergency lighting system when through accident or other cause the regular lighting system is extinguished. Where a separate source of supply cannot be obtained for the emergency lighting the feed for emergency lights must be taken from a point on the street side of all service equipment. Where source of supply for the regular lighting system is an isolated plant within the premises an auxiliary service of sufficient capacity to supply all emergency lights must be installed from some outside source, or suitable storage battery; or separate generating unit may be considered the equivalent of such service.

It is apparent that the question of insuring the source of supply is one which is open to considerable discussion, involving, as it does, the reliability of the generating station and various classes of supply lines. Not only do the characteristics of service received from electric central stations and isolated plants have to be considered, but in some cases gas service and other illuminants.

It is evident that conditions of reliability vary considerably in different instances and that leeway must be allowed according to the merits of the particular cases. Where central station service is employed, it has usually been assumed that independent wiring to the street main provides a sufficient safeguard.

There is a tendency in some quarters to require the emergency lighting to be in operation whenever the regular lighting is in use. This comes from the apprehension of deterioration of unused equipment as well as the anticipation of failure to put the emergency lighting into operation instantaneously. In many cases simultaneous operation may involve an excessive expense. The provision of an automatic system, with reasonably frequent inspection and tests, should provide ample protection.

Where the system is not electric the automatic control may present more of a problem.

Most of the codes do not specify what intensity of lighting shall be provided. In New York State the emergency lighting is provided for in the law, while the code specifies one-quarter foot-candle as the intensity to be provided. This value, which might be implied from the intensity table, is being considered for inclusion in other state codes. It seems to be the reasonable value to require for exits, stairs, hallways and passageways, and also for the main aisles of large workrooms. It might, however, involve an unnecessarily high investment in lines and equipment, to provide such an intensity in all work space aisles.

SWITCHING AND CONTROLLING APPARATUS

This provides for the location of controlling switches so that at least pilot or night lights may be turned on at the main point of entrance.

Some commissions have considered it important that watchmen and others should be able to go about safely without lanterns, while others believe that the carrying of a lantern is sufficient. The former certainly has advantages, but may in some instances be unnecessarily expensive.

It would appear that the rule in this form is satisfactory on the assumption that an industrial commission would make exceptions where unnecessary hardship is shown.

ENFORCEMENT

Attention has been called to the readiness and willingness of the industries to comply with commission regulations, if they are understood.

Other limitations of the code have already been discussed, but none of these has presented more of an obstacle than the fact that many of those by whom the regulations must be applied are not versed in the principles of light and illumination, and have but little idea of the qualities and quantities necessary for the definition of lighting conditions.

Every effort has been made to simplify the rules and make them understandable to others than engineers. Some of the commissions have included simple definitions of terms used. Some have attached explanatory treatises and articles on methods of designing lighting installations. But there is still a need for more popular education. The possibilities of rendering the codes more definite and accurate in the future depend in a considerable degree on such education.

Undoubtedly the commissions can take care of their inspectors but the small manufacturers, foremen and others responsible for the construction and operation of industrial lighting installations need assistance.

The codes and their appendixes will undoubtedly provide effective mediums, but the help of those professionally related to the lighting practise is needed. It is earnestly hoped that the individual members of the American Institute of Electrical Engineers and the Illuminating Engineering Society, will inform themselves regarding the principles of the code specification and not only offer constructive criticism but also help in the educational effort of applying the regulation.

CONCLUSION

The author is inclined to look with apprehension upon laws or regulations emanating from the professions whose business they affect most directly. There has sometimes seemed to be a tendency in such legislation to favor the profession. Such tendencies are presumably more due to the professional viewpoint or prejudice, than to any intent to be unfair.

Having been connected from the first with the committees responsible for the illuminating engineering features, it is only fair to say that the danger of prejudice has been anticipated and carefully guarded against.

Especial care was exercised in the make-up of the committees and the solicitation of criticism, not only to represent the viewpoint of every phase of illuminating and other engineering, but also the light user and light purchaser. The engineer, the scientist and the practical constructor and operator were all included.

On the other hand, it is even more dangerous to legislate regarding such a technical subject without the guidance of the profession. In lighting we have numerous examples of such legislation as, for example, in the headlight laws for railways and automobiles. Many of these laws are not effective or reasonably enforcible, their meaning is not clear, while they not only impose unnecessary hardships, but have in some cases prescribed a dangerous rather than a safe condition.

The industrial lighting codes, besides avoiding both of these dangers, have been so formulated as to encourage uniform action throughout the various states of the Union. The continuation of the code development along the present lines is therefore of importance not only to those directly interested in the electrical and illuminating phases, but to the country as a whole.

In discussing the codes an attempt has been made to emphasize the principles involved rather than the details. Changes in details may be expected, but any considerable change in principles seems unlikely. No one is more conscious of the limitations of the code in its present form than the illuminating engineers who have been active in its development, but all who have had anything to do with the work regard it as a valuable working instrument. The author feels safe in saying that they consider it highly important to any state that it be adopted and actively applied as soon as possible. The greatest possibility for future development is through the experience and popular education following its enforcement.

The author has tried to avoid the expression of personal opinion as far as practicable. He has sometimes found it desirable to express his understanding of the views held by committees and their members, but this has been informal and unauthorized and should be so understood.

He herewith acknowledges with thanks the helpful assistance in the way of comment and criticism of Mr. L. B. Marks and Professor C. E. Clewell, to whom perhaps more than to any other individuals we are indebted for the initiation of these constructive regulations.

The author also acknowledges the assistance of Mr. J. A. Hoeveler and others.

BIBLIOGRAPHY

1. "The Mechanical Engineer and the Prevention of Accidents," by John Calder, *Journal* American Society of Mechanical Engineers, February, 1911,

2. "Illumination as a Safety Factor in Industrial Plants" by R. E. Simpson, *Transactions* of Illuminating Engineering Society, Vol. 9, No. 5, page 459. Also *Electrical World*, April 18, 1914, page 858.

"Illumination and One Year's Accidents" by R. E. Simpson, *Transactions* of Illuminating Engineering Society, December 30, 1915, page 868.

"Relation between Lighting Curtailment and Accidents" by R. E. Simpson, *Transactions* of Illuminating Engineering Society, Vol. 13, No. 8, page 429. Also *Electrical World*, November 16, 1918, page 935; *Central Station*, November, 1918, page 156, National Electric Light Association *Bulletin*, October, 1918, page 536.

"Relation of Industrial Lighting to Safety" by C. E. Clewell, *Electrical World*, June 16, 1917, page 1153.

3. "Illumination and Eyestrain" by E. M. Alger, *Transactions* of Illuminating Engineering Society, March 1913, page 130.

"Conservation of Vision" by E. M. Alger, *Illuminating Engineer*, February 1912, page 618.

"Hygiene of the Eye" Wm. Campbell Posey, A. B., M. D. (published by J. B. Lippincott Co., Philadelphia and London).

4. "Code of Lighting Factories, Mills and Other Work Places, *Transactions* Illuminating Engineering Society Vol. 13, No. 4, page 256.

5. "Lighting Legislation" L. B. Marks, *Transactions* Illuminating Engineering Society, February 1916, page 40.

6. "Productive Lighting Intensities" W. A. Durgin, *Transactions* Illuminating Engineering Society, Vol. 13, No. 8, page 417. Also *Electrical Review*, November 2, 1918, page 686.

7. "Factory Inspectors Study Industrial Lighting" by C. E. Clewell, *Electrical World*, July 6, 1918, page 11.

8. "Instructional Session for Special Guidance of State Factory Inspectors, held in Boston, October 31st, 1918" *Electrical World*, November 9, 1918, page 904.

9. First Report of the Departmental Committee on Lighting in Factories and Workshops, Home Office, British Empire, London, England, published by Eyre and Spottiswoode, Ltd., East Harding Street, E. C., London, England.

10. "Effects of Brightness and Contrast on Vision" by P. G. Nutting, *Transactions* Illuminating Engineering Society, Vol. 11, No. 9, page 939. *Electrical World*, February 17, 1917, page 326.

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UTILIZING THE TIME CHARACTERISTICS OF ALTERNATING CURRENT

BY HENRY E. WARREN

ABSTRACT OF PAPER

By the invention of a very small, simple and reliable self-starting synchronous motor, in conjunction with convenient means for regulating the average frequency of an alternating circuit, there has been developed a new field of usefulness for electric power. It is now feasible to drive all kinds of timing devices such as clocks, graphic instrument movements, time recorders, etc., directly from the lighting circuits. Remarkable accuracy is obtained, and the amount of care is minimized by the elimination of winding and regulating.

MORE than a decade ago the possibility was recognized of increasing the accuracy of the alternations of current distributed for light and power to a degree where it might serve through synchronous motors to drive ordinary clocks. The system proposed, which was said to have been actually tried in Germany, was inadequate in using motors which required to be manually started and in the mechanism for enabling control at the central station.

Within a few years the author, impressed by the great opportunity to extend the use of alternating current into the field of clocks and various timing devices, recognized that the first requirement was a very small reliable self-starting synchronous motor. After many experiments the motor shown in phantom view in Fig. 1 was developed. This has a small bipolar field magnet, fitted with shading coils on its poles, and is excited by a winding *A* taking current from a single phase circuit. Located in the field with a relatively large air gap is a disk rotor *B* with projecting pins *C*, the rotor and pins being made of hardened magnet steel. The rotor is mounted upon the shaft *D*, which is vertical to reduce wear of the bearings; and the relation between the rotor and the field is such that the weight of the former, which is only 1/20 of an ounce, is magnetically supported, so that when running it floats without appreciable end thrust. Motion from the rotor shaft is transmitted through the worm thread *E* to the gear *F* and thence by another similar reduction to the terminal shaft *G*. This gearing is enclosed in a nearly air-tight case *H* which contains an ample amount of lubricating oil. The worm thread on the rotor shaft forces this oil through the upper bearing and distributes it to all rubbing surfaces. The space around the rotor is guarded from entrance of dust and loss of oil by a tight cap of non-magnetic metal which is sealed into the case.

The rotor of this motor starts from rest and runs at synchronous speed because of the magnetic remanence in the hard steel. The initial starting torque is due to the fact that the poles induced in the disk by the rotating magnetic lines of the field persist locally during part of an alternation after the inducing magnetism has advanced, and by ordinary magnetic attraction tend to follow the field. The following reverse magnetic alternation overpowers these local poles in the rotor disk and sets up new ones, but the disk has moved meanwhile. At first there is a progressive shifting of the poles through the mass of the rotor. As the speed increases the driving torque continues strong until actual synchronism is reached, when the local poles in the rotor remain in step with the rotating field and no longer shift progressively through the mass of the rotor. In order for this action to take place, it is necessary to proportion and design the field, airgap, and rotor so as to maintain certain very definite relations among them, especially with regard to the distribution and intensity of the magnetic flux. Otherwise the magnetic poles of the rotor will shift at synchronous speed and the rotor will slip.

The rotor pins *C* considerably increase the synchronous torque of the rotor without interfering with its starting torque, but they must be properly proportioned and arranged to accomplish this result. Material such as is used for permanent magnets serves better than ordinary carbon steel for pins and rotors. Apparently the higher the remanence the greater the output.

The general appearance of the motor is shown in Fig. 2. The overall dimensions are 2 3/16 inches high, 2 11/16 inches wide and 2 5/8 inches deep. The weight is 15 oz. One of these motors consuming about two watts will deliver at its terminal shaft, making one rev. per min., slightly more than one-millionth of a horse power. Its efficiency is therefore one twenty-fifth of one per cent. Nevertheless, this minute amount of power is more than ample to drive clocks and various forms of timing devices. In fact it represents several times the output of a strong spring clock movement. These synchronous motors will start and run indefinitely at absolute synchronism when connected in circuit of the approximate frequency for which they are designed. Their synchronous operation is not affected by very considerable changes in voltage. For example, they will operate correctly when the voltage is 50 per cent above or below its normal value, but a motor designed for 60 cycles requires certain changes in its proportions in order to operate properly at 25 cycles. There is, however, no difficulty in supplying motors to operate at any standard frequency.

The starting torque of these motors is more than 50 per cent of their running torque. If overloaded beyond capacity they will generally come to rest and will not continue to run below synchronous speed. The period during which a motor will run without attention has not yet been determined, but some of them have been operating continuously 24 hours per day for more than 2½ years. It is evident that the lubricating oil which they contain should be renewed every year or two and if this is done, there seems to be no reason why the motors, when driving light loads such as clocks, should not run for many years. The oil can be easily renewed but the motor has its parts sealed together when it is built. The only place where the oil can escape is through the clearance space around the terminal shaft, but this is above the oil level when the motor is in operation. Owing however to variations in air pressure and temperature changes, a very slight amount of oil is occasionally forced out at this point.

The next requirement in order to improve existing distributing systems so that they might be used for the operation of clocks and other timing devices was an instrument which could be used in place of the present frequency meters to standardize the frequency at the generating station. The result achieved is shown in Fig. 3, which illustrates the type of master clock that has been installed in many of the principal power stations in the eastern part of the United States, and which has been adopted for controlling the frequency.

This clock contains two complete movements, one regulated by a pendulum and the other driven by one of the self-starting synchronous motors which have been described. On the large dial of the clock there are two hands, one of them black and the other gold. The black one represents the time as determined by the pendulum. This pendulum has a rod of invar and its rate is adjusted by two methods. One used in astronomical timepieces consists in adding or subtracting weights on a small platform carried by the pendulum rod. These weights are numbered to indicate the seconds per day which they will alter the rate. The other method is electromagnetic and consists in passing a very minute measured current through flat coils located below the pendulum bob. Within the pendulum bob there is a permanent magnet, the field of which cuts across the conductors of the coils. This combination of parts permits an exceedingly accurate adjustment of the rate of the clock. It is easy by this means to make the clock run a fraction of a second per day faster or slower.

The other hand which is mounted upon the large dial and is gold in color, is driven directly by gearing from one of the self-starting synchronous motors. The gear ratio between the hand and the motor is such that at normal frequency the gold hand will revolve at exactly the same rate as the black hand, and if they are started together they will remain so. These hands make a complete revolution in five minutes.

The operators at the switchboard are instructed to look at the clock occasionally and, if they find that the gold hand is gaining over the black hand, to lower very slightly the speed of the turbines. If the gold hand is running behind the black hand, the turbine speed is to be slightly increased. Small momentary variations in the frequency do not perceptibly affect the relative position of the gold and black hands, and since in general these fluctuations are equally likely to be positive and negative, there is shown only the error which is cumulative. Any real tendency of the speed to run either higher or lower than its normal value will gradually bring about a change in the relation of the two hands. This is really the only error in the frequency which should be corrected by the operator, because the governors of the turbines will automatically take care of the momentary fluctuations. The master clock may be considered as a device to maintain a true base line for the frequency.

The physical effort required to maintain this correct base line is very much less than has formerly been expended in some large systems in trying to keep the frequency correct by following, the indications of an ordinary frequency meter. The reason for the difference is that the frequency meter shows only the instantaneous value and is consequently fluctuating above and below the average value. These fluctuations are only momentary as has been pointed out before, but there is no way by which the operator can tell whether the indication of the meter when he looks at it represents a high point in the frequency curve or a low point. Consequently, he is obliged to assume that it represents the average frequency, which it rarely does. Therefore when he adjusts the speed according to a reading of the frequency meter, he may make the average value worse than it was before. The next time he looks at the meter, the needle may happen to be on the same side of the average, in which case the operator assumes that he did the right thing previously. Or it may happen to be on the opposite side, when he concludes that it needs new adjustment in the reverse direction. The more frequently these adjustments are made, the more necessary they apparently become. The difference between determining frequency by the frequency meter method and that of the master clock may be made clearer by the following somewhat analogous illustration:

Suppose that a lake, the surface of which is covered with waves, is to have its depth measured. One method is to go out in a small boat and drop a sounding line overboard. The observer will be able to tell the depth of the water within a foot or two, but the readings which he makes will be constantly varying on account of the motion of the waves. This corresponds to the frequency meter method. A much more accurate means of determining the depth of water in the lake would be to enclose a considerable area of its surface in a structure such that the waves could not enter and the surface of the water would be smooth and level inside. Then a reading by a sounding line would instantly give the true depth. This corresponds to the master clock method.

With the master clock method, the only error that appears is a real one and is due to the tendency of the average frequency to run either high or low. This tendency in a large station may not become manifest for a considerable time interval, sometimes as long as 30 minutes or more. Therefore it is not necessary for the operator to make adjustments nearly as often as he did formerly where he depended upon the frequency meter. Perhaps it would be fair to estimate that one-half or one-third as many adjustments are needed where the master clock is used.

The only care which must be given the master clock is to compare it every few days with accurate time signals sent out from Washington or some astronomical laboratory. When it has been carefully regulated it should run within a very few seconds a week. If conditions are favorable one of these clocks will keep within one or two seconds per week. The winding of the movement which drives the pendulum is done automatically by the same motor which is geared to the gold hand on the large dial. As a safe-guard a second motor which drives a clock hand moving over a small dial is installed in the same case. In an emergency this hand can be used to regulate frequency by comparison with the black hand on the large dial. There should also be installed on the wall near the master clock a secondary clock with a second hand driven by one of the small synchronous motors so as to check at all times the frequency on the system. The master clock itself should stand upon a reasonably firm foundation so that it will not be subject to excessive vibration. Its motors, which require only four watts, may be connected to any nearby instrument transformer which can be depended upon to remain in circuit continuously. The effect of controlling the frequency by one of these master clocks may or may not be apparent on the frequency meters which have been in use. This will of course depend upon the error of these instruments. If however the average frequency is measured by more sensitive means, for example, by counting the total number of alternations during the day and determining the average mathematically, the effect of the master clock will at once be apparent. Any ordinary frequency meter can hardly be expected to keep the error in the average frequency below one or two per cent, while the master clock will easily, over a 24-hour period, keep the error in the average frequency below 1/100th of 1 per cent.

Ordinary frequency meters are subject to errors principally of the following kinds:

1. Calibration.
2. The effect of use and time.
3. Variations due to temperature.

Of the foregoing errors those due to calibration and use may be overcome by frequent recalibration, provided an accurate standard is available, which is not usually the case; but the errors due to temperature are very difficult indeed to eliminate

PLATE XXXI.
A. I. E. E.
VOL. XXXVIII, NO 5

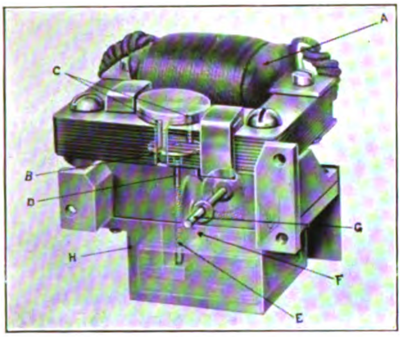


FIG. 1

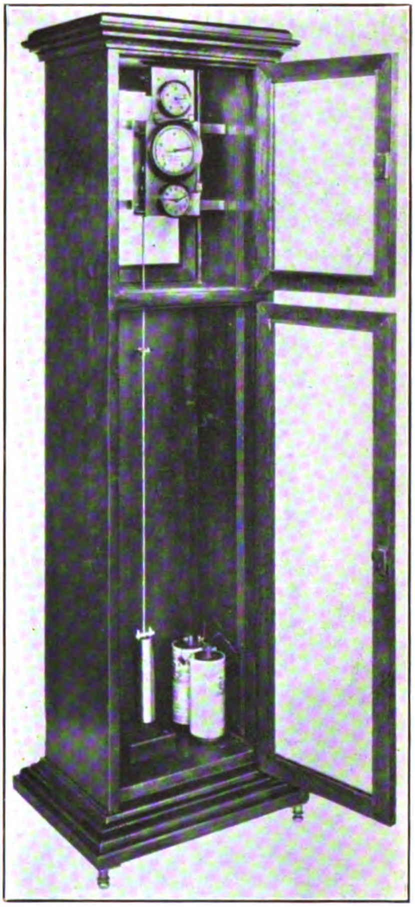


FIG. 3

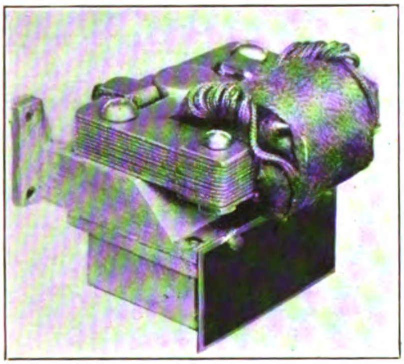


FIG. 2

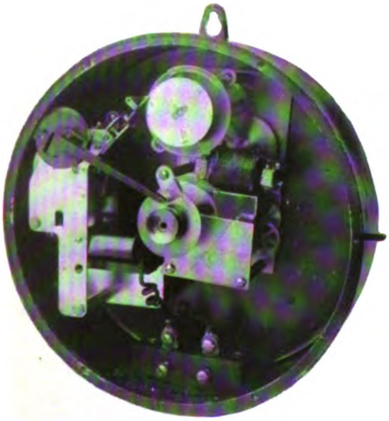


FIG. 5

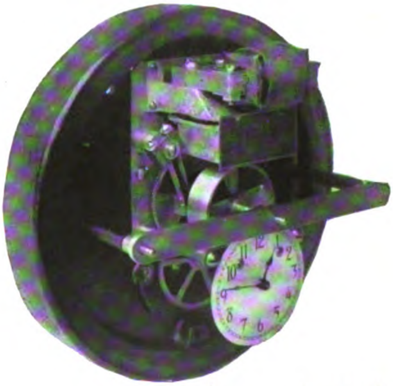
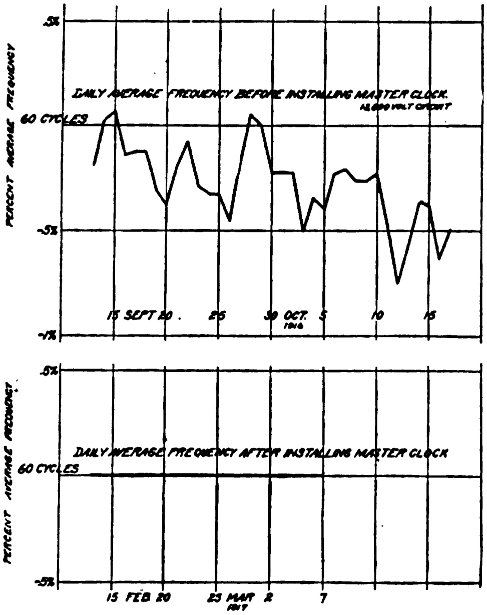


FIG. 6 [WARREN]

and these errors alone will ordinarily justify the master clock method. There is no reason why the frequency of a great system should be dependent upon the temperature at the switchboard, which has generally been true.

In Fig. 4 is shown an interesting comparison between the frequency obtained on a very large system by means of first class frequency meters which were often checked and conscientiously watched, and the frequency on the same system at a later period when the regulating was done by means of a master clock.



BEFORE AND AFTER

The effect of the installation of a master clock is here strikingly illustrated. Note the marked irregularities with the best regulation possible under the old system.

FIG. 4

The errors in the former case were principally due to variations in temperature, and these during the whole year covered a considerably wider range than shown in the curve, which covers only one month. These two curves do not represent all the variations in frequency during each day, but only the average value of the frequency as determined by dividing the total number of alternations during the day by the time in seconds. They may be said to form the base lines of the frequency. In one case the base line is very irregular and differs materially from its normal value, and in the other case it is a horizontal line having true normal value with an error too small to show on the plot. Experience has shown that where master clocks have been installed on various systems the average frequency before the master clock was started has usually been as much as one or two per cent above or below normal, although of course it was impossible to determine this until the clock began to operate.

The question will immediately arise whether there is any advantage in trying to hold the average frequency nearer than one or two per cent to its exact value, and superficially there might appear to be no good reason for doing so. Certainly the customers will be unable to tell the difference, because frequency meters which they may have are not better than those at the central power station, and there has been no other easy method of showing the error.

On careful analysis however, it will be apparent that there is a real advantage in keeping the base line of the frequency at its true normal value. In the first place, the machines connected with the system, including the turbines, are so designed as to run most efficiently at normal frequency. Some of these machines, for example hydraulic turbines, may have either their efficiency or their output materially affected by deviation from normal speed.

Perhaps the most obvious effect of errors in the frequency is upon those manufacturing establishments whose output comes from continuously running machines, particularly where textiles, paper, or flour are made. It is a well-known fact that textile machinery can be driven up to a definite speed with a constantly increasing output, but not beyond this without injury to the product. Now whether induction or synchronous motors are driving such machinery, the speed will depend directly upon the frequency. Consequently, if the average frequency is even one per cent lower than the most efficient speed for the machines, the output of the mill per day will be diminished by just that same percentage, and if the frequency is higher the product will suffer injury. The fact is of course recognized that it is necessary to allow a certain margin for safety between the average operating speed and the maximum speed to take care of temporary variations caused by load fluctuations or otherwise, but this same margin must exist in any case. It is clear that the output of a cotton mill connected to the system where the curve in Fig. 4 was made would be greater during the summer season when the frequency was nearly normal than later in the season when the frequency dropped, because of the temperature coefficient of the frequency meter. In a number of textile mills connected to a single system, the value of the lost output in dollars and cents due to this cause would soon exceed the trifling cost of the master clock equipment necessary to standardize the frequency. In paper mills the evenness and quality of the paper depend upon the accuracy and uniformity of the speed, so that there is a very obvious financial advantage in maintaining correct frequency. Doubtless many other classes of manufacturing are similarly affected, but the above examples are sufficient to show the financial desirability of the new method.

Beside the advantage to the user of electric power in maintaining the correct average frequency, there is a definite psychological advantage to the operating engineers and managers of power companies in being able to assure themselves and all of their customers that they are maintaining the frequency upon which they have agreed. A still greater gain from the standpoint of the power producer results from the ease with which systems having such standardized frequency may be connected in parallel without the slightest disturbance. Generally, where many systems are feeding into a large network, the individual variations in the frequency meters are such that it is necessary to make adjustments by raising or lowering the speed, sometimes to a very perceptible extent, before an individual station can come into synchronism with the network; but where master clocks are installed it is only necessary to wait until the machines have the right phase relation, because there will be no measurable difference in the average frequency of the independent station and the network when they are running independently. As at the present time the tendency is very clearly to increase the interconnection of big power producers towards the ultimate goal of a complete union extending all over the country, it is obvious that preliminary standardization of the frequency is a step in that direction.

Passing now from the advantages of master clock control which affect existing service, one comes to gains which open an entirely new field of service. Just as soon as the frequency of a system has been controlled by means of a master clock, it becomes feasible to connect anywhere in the line small self-starting synchronous motors like Fig. 2 and use them to measure time accurately. The most obvious use of such motors is to drive clocks, and this is being extensively done. Such clocks may ultimately supersede a large proportion of the spring- or weight-driven clocks that are in use today. Obviously the new clocks never need to be wound nor regulated and they will keep time in a manner which is most astonishing to one familiar with the poor time-keeping qualities of an ordinary clock. On a well regulated system these motor-driven clocks can be depended upon to remain correct within a few seconds, month after month. This requires that provision be made against interruptions of the service, which will be mentioned later.

To the electric light companies the great immediate advantage of the new kind of service is the ability to substitute these self-starting synchronous motors for the troublesome and unreliable clock movements that are used at present to drive graphic meters, maximum demand recorders, and similar devices. It is well known that these various kinds of meters require a large amount of attention to keep them wound, regulated and in repair. This is particularly true of the maximum demand recorders, which are distributed widely over large systems and thus require a great deal of traveling to keep them in operation. Substituting motors does not of course eliminate all attention, because it is still necessary to change the record sheets occasionally; but in many cases the recording time can be extended either by using larger paper rolls or a slower feed, and in all cases the attention for winding and frequent regulating is eliminated. It might be expected that these meters would, when motor-driven, give much more accurate records, and this has been found true. In the first place, the motors are far more powerful than the clocks and they are not affected by the varying friction of the paper feed. Therefore it has been found feasible to make better records by using more tension on the paper. Frequently such recording devices are used to analyze the cause of disturbances, and in such cases it is of great importance that the records should be synchronous. This is impossible where ordinary clock movements are used. Where there is a difference between two records, there is always more or less doubt whether this is due to an error of the clocks or not; but where synchronous motors are driving the recorders there need be no uncertainty in this respect. On account of the very small size of the motors shown in Fig. 2 it has been found easy to substitute them in all kinds of recorders where spring-driven clocks have been used. Fig. 5 shows a complete movement driven by one of these motors, suitable for a maximum demand recorder. There are certain instruments in which periodic contact making is required, and in these, this motor is equally well adapted to replace the clocks. Fig. 6 shows a printometer equipment whereby a circuit is closed for a fraction of a second every fifteen minutes. This interval is as exact as the regulation maintained by the master clock at the power station.

There is another class of instruments which have not come into as general use as they deserve, very largely because of the objectionable features of spring-wound clocks. These are time switches used to control sign lighting, street lighting, and for other purposes. Several forms of time-switch operated by motor have been designed which are in many ways more satisfactory than the ordinary types of time switches. Fig. 7 shows one of these switches with a capacity of 15 amperes designed for controlling street lights. The outside dimensions of this switch are as follows: height 4¾ inches width 2 7/8 inches depth 5 5/8 inches. It will be recognized that this is very much smaller than any kind of clock-driven time switch; it is in fact so compact that when encased it may be placed inside the iron pole of a street light. The advantages of such a switch are obviously the elimination of the winding and regulating, which have always involved a great deal of attention.

In the field of pure timing devices, the most important use of the motors is probably the driving of ordinary clocks. In some respects this is the easiest adaptation of the motor, because the power required is exceedingly slight and the necessary mechanism comparatively simple. As an illustration of the small power output needed, Fig. 8 shows two clocks, the one above with a 2½-in dial and the one below with a 36-in. dial, the latter a comparatively large clock for indoor use. Nevertheless the tiny motor which is also shown in the photograph is equally adapted for driving either of these clocks. Indeed, this small motor can drive still larger clocks. In order to indicate the almost inconceivably small power required to drive the hands of a clock through well-made gearing the following measurements were made:

Diameter clock dial	Hands	Horse power required with ample margin for safety
4 inches	unbalanced	0.0000000017
8 "	unbalanced	0.0000000022
12 "	unbalanced	0.0000000027
14 "	balanced	0.0000000014
Safe output of motor at synchronous speed		0.000001

These tests were made by measuring that torque which was more than ample to drive the train of gears and the hands in their most strongly resisting position. From these figures it is clear that any moderate size clock requires an amount of power which is negligible as compared with the output of one of these small motors.

In the driving of clocks it is necessary to make provision against interruptions in the supply of current, which would of course show as lost time on the dials, owing to the temporary stoppage of the motors. In a large modern power system, especially in the neighborhood of big cities, the interruptions are infrequent and generally of short duration, but they must be reckoned with. Two different devices are provided to safeguard these motor driven clocks against interruptions in the current. The simplest of these devices consists of an indicator which can have two positions. So long as the current flows continuously the indicator is not apparent on the face of the clock, but after an interruption lasting more than a few seconds this indicator appears on the dial and remains there even after the current is restored, thus showing and stating that the clock should be reset. For a brief interruption of the current the indicator, after appearing momentarily, returns to its hidden position. The device is magnetic and exceedingly simple and reliable.

The other means for guarding against interruptions consists in providing an auxiliary spring driven movement connected by differential gearing to the hands of the clock. This movement is at rest so long as the current flows through the motor, because its pendulum of magnetic material is prevented from vibrating by the field magnet of the motor. When an interruption occurs however, the pendulum is released so that the spring driven movement can drive the hands for the time being. Just as soon as the current is restored the pendulum is again stopped

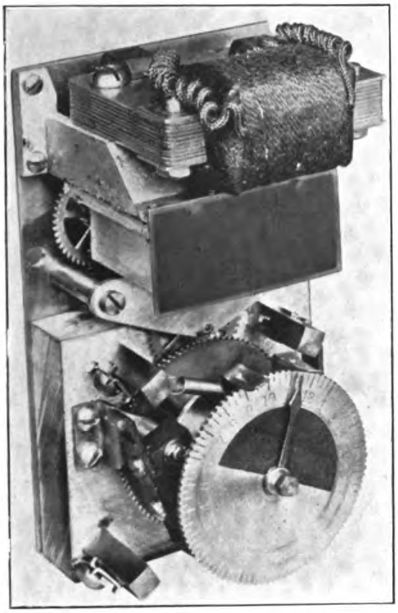


FIG. 7

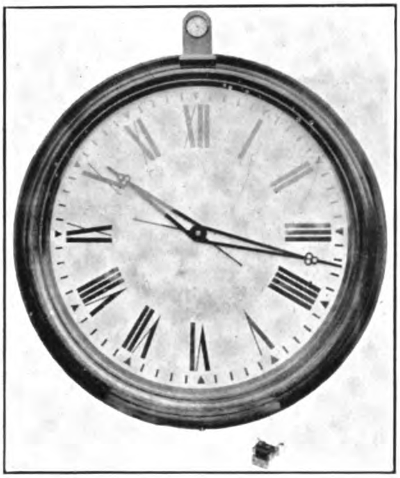


FIG. 8

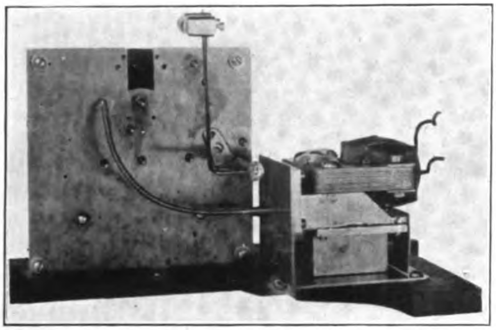


FIG. 10

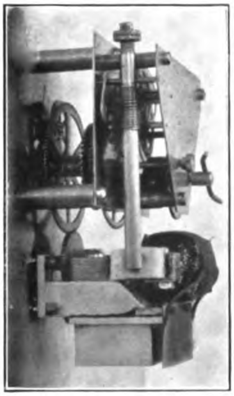


FIG 9 [WARREN]

and the hands are driven through the motor. The spring movement is capable of driving the hands of the clock for 24 hours. It has not been deemed necessary to provide a very accurate auxiliary movement in these clocks, because it is not expected that the current will be interrupted for long intervals, and the error during a short interruption is very slight even if the auxiliary movement does not keep particularly accurate time. As shown by the illustration of the works for the auxiliary type in Fig. 9, this movement occupies very little room, and can be enclosed in any ordinary case. It is expected that as their use becomes widespread, these clocks will be available in all kinds of cases and at prices which compare favorably, considering their advantages, with common spring-driven clocks. After trying them people quickly realize their great advantage as compared with all other kinds. These advantages may be summed up briefly: Extreme simplicity; elimination of winding and of regulating; far greater precision in time-keeping; the ability to get time service from any lamp socket; low cost of maintenance; the avoidance of expensive and troublesome local master clocks and local independent wiring systems; the elimination of batteries, charging sets, relays, etc; and the avoidance of contact mechanism in the clocks themselves.

The service which these clocks give is so valuable in comparison with the cost of the current which they consume that their use can be extended far beyond the field that can be economically covered by existing systems for distributing time. Barring interruptions, the accuracy of time-keeping of the clocks is measured by the care given to the master clock at the power station. On the Boston Edison system where these clocks have been in use for about 2½ years, the service is so good that the clocks seldom vary more than 5 or 6 seconds from the true time. This is a degree of precision which is closer than can be read unless they are provided with second hands. Moreover, this remarkable quality of service really requires, as has been stated before, less attention from the station attendants than had previously been given where frequency meters were used for regulating purposes. The clocks are not absolutely noiseless but they are quieter than any ordinary clock which ticks. It is hoped that ultimately the very slight humming sound which they emit can be entirely suppressed, but this is to most people practically unobjectionable.

The clocks are not affected by temperature changes unless subjected to cold so intense as to thicken the lubricating oil. Different kinds of oil are used for different kinds of service. In some cases ordinary kerosene oil has been employed. This will enable the motor to run at very low temperature. The lubricating qualities of the oil do not seem to be of importance, because the friction of the moving parts is so exceedingly slight. Variations in voltage do not affect the operation of the motors in driving the clocks. A drop in potential of 50 per cent will not trouble the time-keeping qualities of the motor; but with auxiliary movements some difficulty has been experienced when the potential falls to a point where the pendulum of the auxiliary movement is released or permitted to vibrate while the motor also continues to run. In such a case the clock tends for the time being to gain. This could rarely happen in a first class distributing system. The objection does not apply to the indicating type of clock.

The field magnet winding for the motor is so well insulated layer by layer and from the ground that it will stand severe surges of potential due to lightning discharges. The windings are usually designed for 110 volts but potential above 2000 volts has been applied briefly in tests without causing damage. The fire risk of the clocks is evidently negligible and they are approved by the Underwriters' Bureau.

An important use for these clock motors appears to be the driving of time recorders, cost keeping devices, time stamps etc., for offices and factories. There are thousands of such appliances in manufacturing establishments which at the present time are operated by spring driven clocks or in some cases electrically by impulses from local master clocks. Spring driven clocks are objectionable because they require winding and regulating, and where a number are used in the same factory they cannot be depended upon to remain in synchronism. The electrically driven recorders installed hitherto are objectionable on account of the great expense of installation which requires wholly independent wiring and the trouble and cost of maintenance of batteries, charging devices, etc. Because of the ability to connect with the ordinary lighting wires of a factory, these time recording devices may, if driven by the new motors, be located almost anywhere without extra cost. The entire burden of winding and regulating and a large part of the cost of maintenance of the system are eliminated. It is in many cases feasible to attach the new motors to the old movements by a simple device such as a closely wound spiral spring serving as a coupling as shown in Fig. 10.

The indications are strong that as the district supplied by alternating current with accurately controlled frequency extends and this new service becomes ultimately available everywhere, there will develop many new and unforeseen uses for these small self-starting synchronous motors. Combining the functions of a wonderfully accurate clock with those of an exceptionally simple and reliable electric motor, a new instrumentality is available which can be adapted to cooperate with many kinds of existing devices and lead to the development of others for entirely new purposes.

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TRANSMISSION LINE RELAY PROTECTION

BY H. R. WOODROW, D. W. ROPER, O. C. TRAVER AND P. MACGAHAN

FOREWORD

As a result of the large development which has been made in the relay practises in the last few years, the Protective Devices Committee felt it was desirable to make an analysis of the transmission line protective relay situation throughout the country and prepare a summary to bring before the profession, experiences of the operating companies with this protective apparatus. With this in view questionnaires were sent out to sixty-one operating companies asking for their experience and present practise in regard to relay protection.

Replies were received from 32 of the operating companies and from these the following general analysis was made of the practise of relay protection for transmission lines.

The nomenclature used by the different operating and manufacturing companies for the various classes of relays is not in harmony and the Protective Devices Committee undertook the work of standardizing the nomenclature which it is hoped will be adopted by all parties so that any particular class of relays will be given a definite name. The following nomenclature has therefore been proposed by the Protective Devices Committee and this nomenclature is used throughout this paper.

PROPOSED RELAY NOMENCLATURE

Electric Protective Relay. An intermediate device by means of which one circuit is indirectly controlled by a change in conditions in the same or other circuits. The relay is ordinarily equipped with contacts to open or close an auxiliary circuit.

Directional Relay. Any relay which functions in conformance with direction of power or voltage or current or phase rotation, etc.

Power-Directional Relay. Any relay which functions in conformance with direction of power.

NOTE: This includes both uni-directional relays with single-throw contacts and duo-directional relays with double-throw contacts. The reason this name is preferred to "reverse power" is that the device is frequently used to function under normal direction of power. Furthermore, in some cases the normal condition of the system may permit power to flow in either direction. Relays for use in either alternating or direct current circuits are to be classed as power-directional relays.

Polarity-Directional Relay. Any relay which functions by reason of a reversal of the normal direction of polarity.

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Phase-Rotation Relay. Any relay which functions by reason of a reversal of the normal direction of phase rotation.

Current Relay. Any relay which functions at a predetermined value of the current. These may be either over-current relays or under-current relays.

Voltage Relay. Any relay which functions at a predetermined value of the voltage. These may be either over-voltage relays or under-voltage relays.

Watt Relay. Any relay which functions at a predetermined value of the watts. These may be either over-watt relays or under-watt relays.

Frequency Relay. Any relay which functions at a predetermined value of the frequency. These may be either over-frequency relays or under-frequency relays.

Temperature Relay. Any relay which functions at a predetermined temperature in the apparatus protected.

Open-Phase Relay. Any relay which functions by reason of the opening of one phase of a polyphase circuit.

Differential Relay. Any relay which functions by reason of the difference between two quantities such as current or voltage, etc.

NOTE: This term includes relays heretofore known as "ratio balance relays", "biased" and "percentage differential relays".

Locking Relay. Any relay which renders some other relay or other device inoperative under predetermined values of current or voltage, etc.

Trip-Free Relay. Any relay which prevents holding in an electrically operated device such as a circuit breaker while an abnormal condition exists on the circuit.

Auxiliary Relay. Any relay which assists another relay in the performance of its function and which operates in response to the opening or closing of its operating circuit.

Signal Relay. An auxiliary relay which operates an audible or a visible signal.

QUALIFYING TERMS AS APPLIED TO RELAYS

Notching. A qualifying term applied to any relay indicating that a number of separate impulses are required to complete operation.

Inverse Time. A qualifying term applied to any relay indicating that there is purposely introduced a delayed action, which delay decreases as the operating force increases.

Definite Time. A qualifying term applied to any relay indicating that there is purposely introduced a delayed action, which delay remains substantially constant regardless of the magnitude of the operating force. (For forces slightly above the minimum operating value the delay may be inverse).

Instantaneous. A qualifying term applied to any relay indicating that no delayed action is purposely introduced.

Where relays operate in response to changes in more than one condition, all functions should be mentioned.

PRESENT DAY PRACTISE OF TRANSMISSION AND TIE LINE RELAY PROTECTION

THERE was a time when the protection of an electrical transmission system with the single generating station and its radial feeders was not a matter of very grave importance. That time, however, has passed and the multiplicity of generating stations with tie lines and parallel feeders have greatly complicated the once simple problem. Furthermore the practise of inter-connecting large transmission systems has brought about conditions which require very serious consideration when laying out a protective relay scheme. An effective sectionalizing relay scheme is necessary in order to secure both continuity of service and maximum efficiency of transmission, and the most complicated system can be effectively relayed if all the conditions are thoroughly analyzed and proper relays, carefully set for both time and current values, are applied.

Most of the large systems of the present day have grown out of a comparatively small beginning, stations and lines being added as required, without taking into consideration the relay problem. As a consequence this problem has, in a great many cases, become rather difficult and it has become evident that the application of protective relays for sectionalizing trouble is one of the principal features to be considered in determining the design of a transmission system. This point should be borne in mind whether additions are being made to an existing system or whether an entirely new system is being designed. Numerous instances could be given, if space permitted, whereby a slightly different design in extending lines and adding stations would have given a much more simple and effective protective scheme.

The same argument applies to the design of an entirely new system, particularly if it is likely to become very complex, and in so far as practical, possible extension should be considered in the original layout so that various methods of protection can be studied and their advantages weighed against possible disadvantages of a design to which they can be applied. It will be found in practically every case, that one of the many sectionalizing schemes now in use can be combined with a proper layout of stations, transmission and tie lines to give proper selective action. Thus the many difficulties encountered when attempting to apply relays to a system laid out without regard for its protection may be avoided. It is therefore of paramount importance that the selective features of various types of relays be thoroughly analyzed before adapting them to any particular system.

The most perfect relay system cannot be expected to give the best results unless the man in charge of its installation and operation be thoroughly competent and familiar with the various precautions to be taken. It is absolutely essential that he know the characteristics and peculiarities of the relays as well as the scheme he is using. Results of experience have shown that an experienced man will secure more satisfactory results from an inferior type of relay than a less capable man can secure from the best equipment obtainable.

In the early days of the development of electrical transmission systems it was the rule to operate all lines radially so that a much simpler and less accurate relay was sufficient for the service required. But when an attempt was made to operate these lines in parallel it became apparent that a more reliable and accurate relay should be used. It was then that the phenomenal relay development which has taken place in the last few years was begun in order to meet the requirements of the operating companies with their various designs of systems. In order to secure the isolation of the proper feeder in case of trouble on these different systems, it has been necessary to bring out designs of several relays.

In the early days it was the practise in applying protective relays to set them in such a way as to prevent overloading the feeders. However, experience has shown that it is not practical to set relays in this way and expect them to give proper selectivity under heavy short-circuit conditions. For this reason the tendency now is to set the relays for short-circuit conditions to disconnect a defective feeder from the system, and depend on the operator to prevent overloading of feeders. Experience has shown that the overloading of a cable for a reasonable length of time is not as serious a matter as it was once considered to be, and it is sometimes desirable to load a cable beyond its rated capacity in order to prevent interruption of service to important customers.

One of the principal factors controlling the settings of relays is the amount of short-circuit current available under various conditions as outlined later in this paper.

The proper type of relays to be selected for protecting transmission lines is dependent upon whether the system is operated radially, in parallel by groups, or in loop, and the time allowable for holding a short circuit on the system. In general, however, the most simple form of relay protection where several parallel feeders are involved is the straight inverse-time current relays which are set to give times of operation which are progressively longer as the source of power is approached. In some cases, however, where an extended system is considered, the time requirements for the relays approaching the generating station are so long that it is considered dangerous or inadvisable to hold short circuit currents on for this period. We believe a delay of two seconds to be the extreme time a dead short circuit should be allowed to remain on a system, except under very unusual conditions.

The introduction of directional relays at points where power is feeding into a station will materially reduce this maximum time setting as these relays can be given a short time setting as outlined later under the heading "Typical Applications of Current and Directional Relays."

Another method of shortening this time is by the use of the balanced system in which case current can only flow through the relay at time of short circuit as outlined later under the heading "Balanced Protection Schemes."

Another method has been developed for shortening this time by the combination of an under-voltage relay with the inverse time current relay as outlined later under "Combination of Under-voltage and Over-current Relays for Protecting Transmission Lines."

For relay protection on tie lines, between generating stations in general, the conditions are somewhat similar to the straight transmission line relay protection if the additional precautions are taken to prevent operation on heavy momentary surges of power that are likely to exist between two or more generating stations at time of synchronizing or momentary disturbances on the system. The relay desired here is dependent to a large extent upon the method of system operation, as in some cases an operating company will want the tie lines to open, in case of trouble on a portion of the system, whereas other companies want these tie lines held rigidly in service in all cases excepting. in case of trouble on tie lines themselves. In the first case shorter time settings are given to the relays and the application of straight inverse time current relays with the possible application of directional relays, is all that is required. In the second case, however, application of some form of a balanced relay, as described later may become necessary. If the tie lines are not to stay in indefinitely, inverse-time current and directional relays with long time settings would give a very suitable operation and allow the tie lines to open in case of more serious trouble on either side of the system.

SAVINGS EFFECTED BY A PARALLEL OPERATION OF FEEDERS

The savings which can be effected by a parallel operation of feeders depends in a large degree upon the design of the transmission system and the ratio of the capacity of the line to the capacity of the individual synchronous converters or transformers, which are supplied by this feeder. In one system supplying converters varying from 500 kw. to 4000 kw. in size together with step-down transformers in substations of 1500 and 3000 kw. capacity and also industrial substations on the premises of customers ranging from about 500 kw. to 4000 kw. in capacity, it was estimated that if the feeders could be operated in parallel then a saving of 20 per cent could be made in the amount of investment. As the installation in question had a book value of about $5,000,000, there was a possible saving estimated at $1,000,000. This company has been operating feeders in multiple for about two years. During this period they have realized nearly 40 per cent of the possible saving in the investment in feeders, and this has been secured by an actual reduction in the number of feeders, notwithstanding a considerable increase in the maximum load.

The same company also reports in the four years preceding the installation of the relays permitting parallel operation of feeders that they averaged 27 burnouts per year which could not be definitely ascribed to external causes, while in the two years since the feeders have been operated in parallel, the corresponding figure was 16 burnouts. This would indicate a reduction of 40 per cent in the burn-outs of cables due to operation of the feeders in multiple, although the cables were actually more heavily loaded. While the time is rather too short to accept these figures as final and conclusive, it apparently indicates that the operation of feeders in parallel reduces the number of troubles due to internal causes.

Testing and Setting Relays

In order to secure the best results from the relays, it is desirable to make a complete check on the current and time settings of each relay on the first installation and at least once every six months thereafter. Although the time for making these tests is determined to a large extent by the operating conditions, we feel that the best results will be obtained if a general plan is worked out for performing these tests at regular intervals.

If selective operation is to be obtained from the relays the greatest care and precautions must be taken in making these tests. The tests should be performed under conditions as nearly equal to the operating conditions as possible which makes it desirable to include the wiring and complete relay equipment in this test.

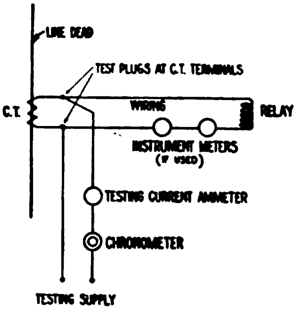


Fig. 1

In this test, wherever practicable, the test current should be applied to the primary of the current transformer. Where it is impracticable to do this the testing current may be supplied to the secondary terminals of the current transformer with the current transformer left in circuit as a shunt as shown in Fig. 1. The results obtained under these conditions very closely approximate those under short circuit and check the relay wiring and current transformer, as well as the relay. This will detect any short circuit in the current transformer or wiring and any open circuit in the wiring but open circuits in the transformer coils should be determined by a separate continuity test.

The degree of accuracy obtained when the relay is tested alone is dependent upon the type of transformer used and the secondary load. The error in this method is due to the high magnetizing current of transformers (especially with the low-ratio single-turn type on heavy secondary loading) on the heavy short circuit conditions. As an example, a 40-volt ampere secondary load on a current transformer at full load imposes a 16-kv-a. load under short circuit conditions of twenty times full load. This, in many cases, is above the saturating point of the transformer and the ratio breaks down badly. The accompanying curves in Fig. 2 illustrate these conditions.

The time-current curve of a relay is affected by the nature of the secondary load or by the current transformer characteristics. It is therefore desirable to test each individual relay with current such as would be occasioned by short circuit. At least three points along the curve should be taken, one of which is approximately 150 per cent of the minimum value, one at as near maximum short circuit current as the testing equipment will permit, and one intermediate point. The time should be taken by a chronometer or cycle counter which will eliminate the personal equation of the operator. The method of timing by a stop watch is entirely inadequate for close relay settings.

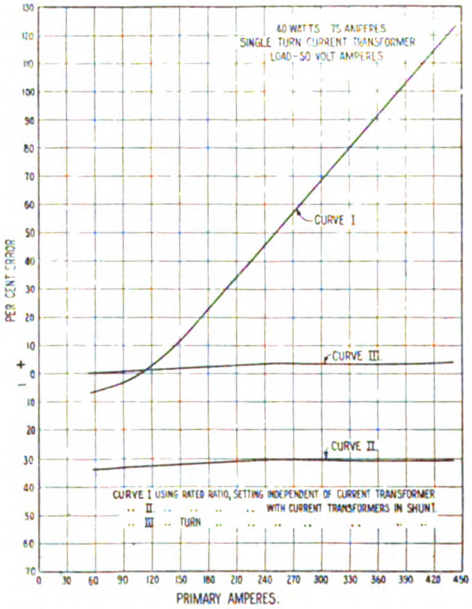


FIG. 2

An additional inspection should be made about every month for continuity of trip circuits (where this is not indicated by lamps) and for dirt or mechanical defects, and where conditions will permit, the relay should be operated to trip the circuit breaker. In case of bellows relays the bellows should be oiled with neatsfoot oil to prevent hardening.

DETERMINATION OF RELAY SETTINGS

For selecting the settings on a relay, it is necessary to analyze carefully the fault currents which will be obtained on the circuits in question under various operating conditions. The limitations on these conditions are usually determined by the number of circuits in operation and the maximum and minimum number of generators connected to the system.

It is desirable to have the relays so set that selective action will be obtained under all probable conditions. It is therefore necessary to check the relay settings against the minimum conditions to be sure that they will operate under minimum connected generating capacity and to also check, the curve for maximum short circuit conditions and allow a sufficient time between the operations of the relays, to permit the opening of the oil circuit breaker and to cover inaccuracies in the relays themselves.

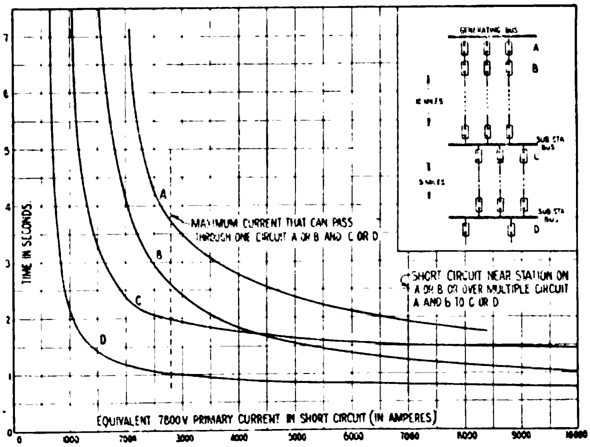


FIG. 3—TIME-CURRENT CURVES OF INVERSE-TIME-CURRENT RELAYS

Where a large number of circuit breakers are in series and selectivity is desired between the several breakers, it is possible to apply, at the various points, relays having different characteristics in order to reduce the time that a short circuit is held on the system near the generating station. The time characteristic curves in Fig. 3 will illustrate a specific case where this method was adopted.

You will note from the curves that the maximum short circuit current that can pass through relays *A*, *B*, *C* and *D*, is 2800 amperes and that the relays at this point are set selective with approximately ¾ of a second between each one successively. Greater currents may pass through circuits *A* and *B* with the short circuit on these feeders near the generating station, and the time characteristic curve being much steeper at this point will allow the relays to open the circuit very quickly. Although the currents through relays *C* and *D* may be much higher than 2800 amperes, these conditions represent times when more than one circuit (*A* and *B*) are operated in parallel and a proper selective action is therefore given with ¾ of a second between consecutive relays under any condition of operation.

The actual determination of short circuit conditions is a rather difficult problem where a network is considered. Various formulas and calculating tables have been developed for simplifying this work which will give a sufficient accuracy for practical purposes.*

The relays in many systems have not been set according to this method but the settings have been determined to a large extent by the results of operation. For instance, if a relay appears to operate prematurely, the settings will be adjusted for a longer time and this will be worked back through the system. This method is very undesirable because either the final settings will be unwarrantedly high or unnecessary interruptions will occur. Moreover, in the meantime results will probably be sufficiently discouraging to cause a lack of interest in the matter. This does not mean that advantage is not to be taken of experience but rather that the basis should be more substantial. Experience should be harmonized with calculation before changes are adopted.

Some companies have made the time of their relay operation longer in order to permit the system voltage to drop in value, thereby reducing the rupturing strains on the oil switches. We point out, however, that considerable precaution should be taken when this is done as the prolonged current may do more damage than the greater rupturing arc in the switch.

METHOD OF TRIPPING

The use of circuit-opening relays for a-c. tripping has not given very satisfactory results, particularly where severe short circuits are possible. It is very desirable to have a definite uninterrupted supply of power for tripping. This has brought into use in many stations the storage battery for this purpose, which has proved to be reliable even in very severe system disturbances.

***G. E. Review*, October 1916 and February 1919; *Elec. Journal*, July 1916.

Some companies have connected their control and tripping circuits to the excitation bus thereby obtaining the advantages of direct current, but sometimes this has led to considerable trouble due to the unstable conditions of this source, especially under a-c. short circuits. It has resulted occasionally in a complete disabling of the control system on account of abnormally high induced voltages on the excitation bus with single-phase short circuits on the a-c. generators. Great precaution should be taken against these conditions and for best results we feel that an auxiliary supply should be used if possible for obtaining at all times a constant power for the tripping circuits.

TYPICAL APPLICATION OF CURRENT AND DIRECTIONAL RELAYS

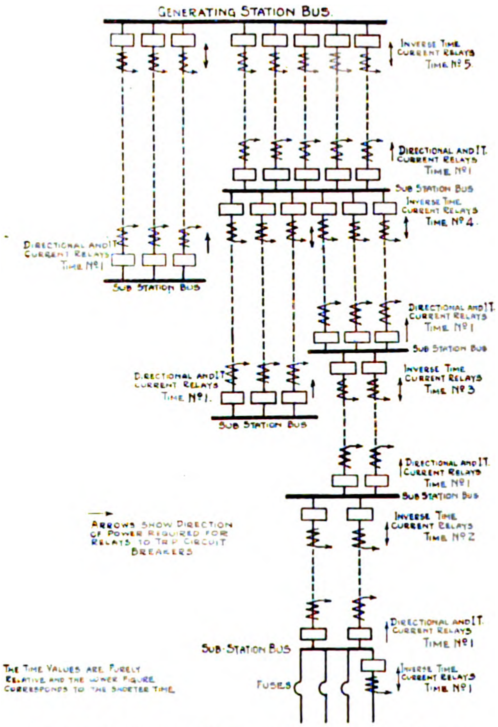
The combination of inverse time current relays with directional relays is becoming very extensively used in cases of parallel operation of lines or of feeders forming a ring system.

Some of the trouble which was experienced in the early days was mainly due to the difficulty in obtaining a directional relay which would operate correctly under all conditions of faults, especially where low voltage was encountered. The directional relays produced at the present time are apparently giving very satisfactory results, even under low voltage conditions down to 1 per cent of normal, and may be applied to loop or parallel group systems in series, in combination with inverse time current relays, if a careful analysis is made of the proposed installation.

For the protection of parallel groups in series, the relays are applied as shown in Fig. 4, with inverse-time current relays placed at the transmitting end and directional relays (combined with an inverse-time current element) at the receiving end. The directional relays are connected to close their contacts for power flowing from the bus to the line, and these contacts are placed in series with those of the inverse-time current relays of the same circuit so that the circuit breaker is tripped only in case of power flowing in the direction away from the bus and of a magnitude exceeding a certain given amount for a certain time. Any time delay required is provided by the adjustments of the inverse-time current relay element.

The settings should be made to suit each individual application and sufficient selective time leeway should be allowed to cover the time of operation of the oil circuit breaker, as well as the maximum probable error in the relay.

For protecting the loop system both the inverse-time current and directional relays (with inverse-time current element) are used as shown in Fig. 5. Each line, at each station, is provided with inverse-time current relays. Where these inverse-time current relays are given the lower time settings, directional relays are also used with the tripping contacts connected in series, so that both relays must operate before the circuit breaker is tripped.

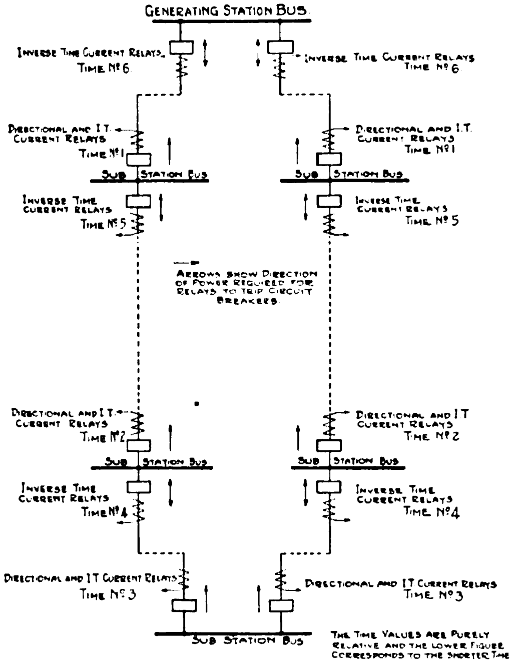

GENERATING STATION BUS.
INVERSE TIME CURRENT RELAYS TIME No 5.
DIRECTIONAL AND I.T. CURRENT RELAYS TIME No 1
SUB STATION BUS
INVERSE TIME CURRENT RELAYS TIME No 4.
DIRECTIONAL AND I.T. CURRENT RELAYS TIME No 1
SUB STATION BUS
DIRECTIONAL AND I.T. CURRENT RELAYS TIME No 1
SUB STATION BUS
INVERSE TIME CURRENT RELAYS TIME No 3
DIRECTIONAL AND I.T. CURRENT RELAYS TIME No 1.
SUB STATION BUS
DIRECTIONAL AND I.T. CURRENT RELAYS TIME No 1
SUB STATION BUS
INVERSE TIME CURRENT RELAYS TIME No 2
ARROWS SHOW DIRECTION OF POWER REQUIRED FOR RELAYS TO TRIP CIRCUIT BREAKERS
DIRECTIONAL AND I.T. CURRENT RELAYS TIME No 1
SUB-STATION BUS
FUSES
INVERSE TIME CURRENT RELAYS TIME No 1
THE TIME VALUES ARE PURELY RELATIVE AND THE LOWER FIGURE CORRESPONDS TO THE SHORTER TIME

INVERSE TIME CURRENT AND DIRECTIONAL RELAYS AS APPLIED TO PARALLEL FEEDERS.

FIG. 4

Reference to the time settings given in the diagram (these are purely relative) will show that they are graded on the same basis as a single series of tandem connected substations, assuming that one end of the loop is open at the generator bus, and neglecting those breakers which would be incoming at the various substations. It should be noted that when the other end of the loop is considered open, the substation breakers which in the first case were incoming will now be outgoing and vice versa. The directional relays are also installed if the time of an incoming line is lower than an outgoing line further from the source. This must be checked separately for each end, in turn, considered opened at the generator station.

In order to secure the operation of the directional relays under bad power factor conditions, the connections are made so that the maximum torque is obtained with lagging power factor. This may be accomplished by several schemes of connections of the potential and current elements, which schemes may not be interchangeable with different types of directional relays. Some operators have found it advantageous when using directional relays with step-down transformers (particularly if not paralleled on the primary side) or reactors, to connect the voltage elements of the relays to the bus side of this apparatus in order to give a higher voltage in case of


GENERATING STATION BUS
INVERSE TIME CURRENT RELAYS
TIME Nº 6
INVERSE TIME CURRENT RELAYS
TIME Nº 6
DIRECTIONAL AND I.T. CURRENT RELAYS
TIME Nº 1
DIRECTIONAL AND I.T. CURRENT RELAYS
TIME Nº 1
SUB STATION BUS
SUB STATION BUS
INVERSE TIME CURRENT RELAYS
TIME Nº 5
INVERSE TIME CURRENT RELAYS
TIME Nº 5
ARROWS SHOW DIRECTION OF POWER REQUIRED FOR RELAYS TO TRIP CIRCUIT BREAKERS
DIRECTIONAL AND I.T. CURRENT RELAYS
TIME Nº 2
DIRECTIONAL AND I.T CURRENT RELAYS
TIME Nº 2
SUB STATION BUS
SUB STATION BUS
INVERSE TIME CURRENT RELAYS
TIME Nº 4
INVERSE TIME CURRENT RELAYS
TIME Nº 4
DIRECTIONAL AND I.T CURRENT RELAYS
TIME Nº 3
DIRECTIONAL AND I.T CURRENT RELAYS
TIME Nº 3
SUB STATION BUS
THE TIME VALUES ARE PURELY RELATIVE AND THE LOWER FIGURE CORRESPONDS TO THE SHORTER TIME

INVERSE TIME CURRENT AND DIRECTIONAL RELAYS AS APPLIED TO A RING SYSTEM.

FIG. 5

short circuit, thereby obtaining better operating conditions for the directional relays.

BALANCED PROTECTION SCHEMES FOR TRANSMISSION LINES

A great many operating companies have installed on a portion of their lines, protective equipment which is designed to be inoperative so long as the currents in different circuits or at different points in the same circuit are substantially equal. To this end, they have made use of (a) fully insulated lines in parallel between stations; (b) conductors in parallel having reduced separating insulation *i. e.*, split conductor cable and (c) pilot wires of relatively small cross-section between the two ends of a line to sense the degree of balance of the currents at these points.

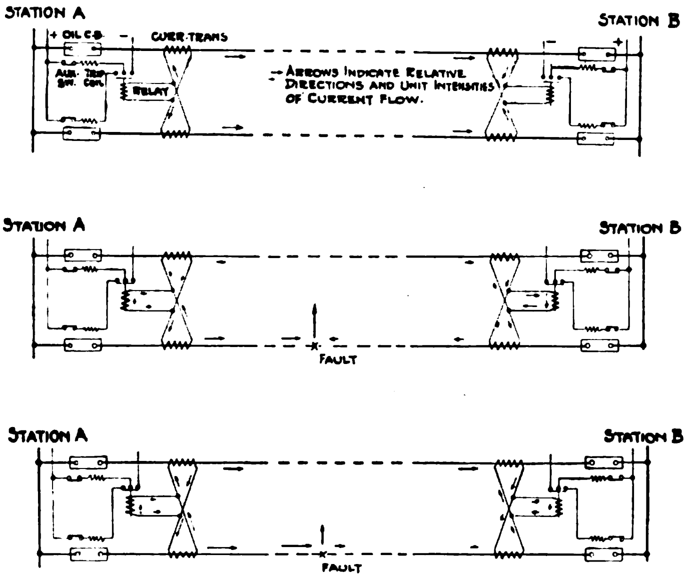
It is impractical to describe here the various modifications of these schemes in detail. However, the basic principles involved are discussed below, which principles are sufficiently flexible to allow application in various ways to the problem which may be in hand.

In the various diagrams accompanying the descriptions of these balances schemes, arrows are inserted to indicate the relative direction of current or of power. These arrows show power normally flowing from station A to station B. In each case, however, the equipment is equally suitable for power flowing in either direction.

In general, the over-current relays used are adjusted to operate instantaneously or nearly so. Some companies report that the opening of the breaker is so rapid that there have been cases where a cable has immediately rehealed, due to hot insulating material flowing into the opening made by the fault. Usually the point of breakdown has been actually located by subsequent inspection.

Balanced Protection of Two Parallel Lines (Not discriminating). An exceedingly simple scheme of balanced protection is illustrated in Fig. 6. This has given excellent results in a system which is so arranged that the lack of discrimination on the part of the relays between the sound and the injured line of a pair is not very vital. On the system referred to, each substation having such relay scheme, is provided with power over at least two different groups of lines. The complete, though temporary, interruption of one of these sources does not therefore kill the bus in question, and no hardship is imposed greater than the inconvenience of determining the good line preparatory to replacing it in service without its mate. This inconvenience is to a considerable extent compensated for by the freedom of the equipment from all alternating-current potential connections. While these potential connections, in present day relays, do not occasion the misgivings they were responsible for in older types, their elimination is a point not to be overlooked.

The balanced equipment as shown in Fig. 6 consists of "cross connected" current transformers in the similar phases of the two lines, to the equi-potential points of the secondaries of which an over-current relay is connected. Reference to the arrows will show an assumed normal current flow, so long as the currents are equal and in the same direction in the two lines, there will be no current to flow through the relay coil, as demonstrated by the arrows on the secondary circuits. A through short circuit will not, therefore, improperly open these circuit breakers providing, of course, the line characteristics are such that a suitable balance is maintained.



Figs. 6, 7 and 8—Balanced Protection for Two Parallel Lines (Not Discriminating)

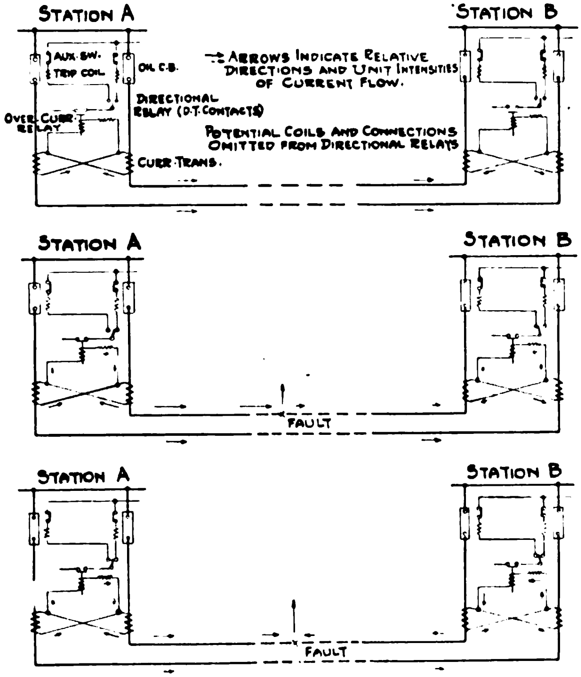
Assume a fault as shown in Fig. 7. In this case there is an unbalance of currents at substation A and a relative reversal of current at Substation B. The differential of the secondary currents pass through the over-current relays, being an arithmetical difference at substation A and an arithmetical sum at substation B. Due to the differential current in the relay coils, the latter cause contacts to close, which trip both circuit breakers at each end of the two lines. Following such operation it is reported to be the practise to find the healthy line and connect it in service with time over-current protection (not illustrated in the diagrams) in place of the differential protection. If, at any time, the fault should occur so near station B that the currents at station A remained balanced, then the station A relay would not operate immediately but at B the differential current would be very great due to the reversal in the relative directions. Station B would, therefore, clear quickly after which there would be established a large differential at A. An open circuit in either of the lines will likewise unbalance the pair and result in its isolation.

In order to protect against short circuits on the substation bus itself, or any possibility which would not give a relative unbalance or relative reversal of current on a parallel group of lines, the generator ends of all feeders are provided with inverse-time limit relays having comparatively high settings. It might be added here that with faults on the feeders between the generator station and substation, the substation relay clears the pair of lines from the substation, usually so quickly that the inverse-time limit relay on the faulty line only at the generator end trips, thus leaving the good line of the pair connected at the generator substation.

Assume now a restricted fault in one of these lines, as in Fig. 8, such that the power direction remains throughout as formerly although the intensities have changed. It will be noted that the resulting difference in the currents in the two lines is reflected in the secondaries where it appears as a current through the relay coils and, causing the contacts to close, trips both circuit breakers at each end of the two sides.

Balanced Protection for Two Parallel Lines. (Discriminating). In order to obtain discriminating action in the relay equipment for short circuits in either of two parallel lines, direction relays are included in the scheme previously shown in Fig. 6. With this modification the arrangement is as illustrated in Fig. 9. It should be noted that in case of an open circuit in one of these, selective isolation of the broken line is not obtained. The resulting unbalance would cause the opening of the sound feeder at one end and of the broken circuit at the opposite end, in case of sufficient current flow, as determined by setting of the time current relay.

As in the previous case, so long as a balanced condition is maintained between the corresponding phases in the two lines, there will be no current in the differential or relay circuit. When a fault occurs, however, the vectorial unbalancing in the main circuits will be indicated in the relay coils as illustrated in Figs. 10 and 11. In these figures the arrows may also be considered as indicating direction of power flow. The moving contact of the directional relay will travel in the direction of the arrow.


STATION A
STATION B
AUX. SW.
TRIP COIL
OIL C.B.
→ ARROWS INDICATE RELATIVE DIRECTIONS AND UNIT INTENSITIES OF CURRENT FLOW.
DIRECTIONAL RELAY (D.T. CONTACTS)
OVER CURR. RELAY
POTENTIAL COILS AND CONNECTIONS OMITTED FROM DIRECTIONAL RELAYS
CURR. TRANS.
STATION A
STATION B
FAULT
STATION A
STATION B
FAULT

FIGS. 9, 10 AND 11—BALANCED PROTECTION FOR TWO PARALLEL LINES (DISCRIMINATING)

Looking at the matter from another view point if we assume for the moment that only one line is in service, then the current

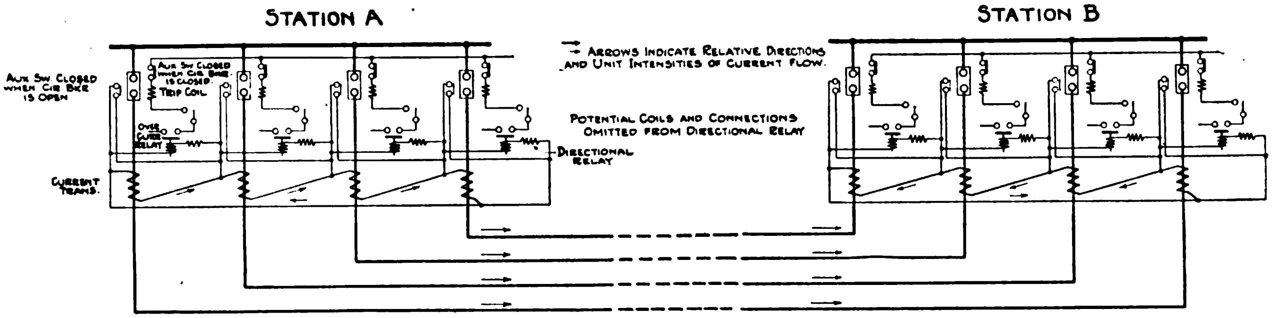

STATION A
STATION B
AUX. SW. CLOSED WHEN CIR. BKR. IS OPEN
AUX. SW. CLOSED WHEN CIR. BKR. IS CLOSED.
TRIP COIL
OVER CURRENT RELAY
CURRENT TRANS.
DIRECTIONAL RELAY
ARROWS INDICATE RELATIVE DIRECTIONS AND UNIT INTENSITIES OF CURRENT FLOW.
POTENTIAL COILS AND CONNECTIONS OMITTED FROM DIRECTIONAL RELAY

FIG. 12

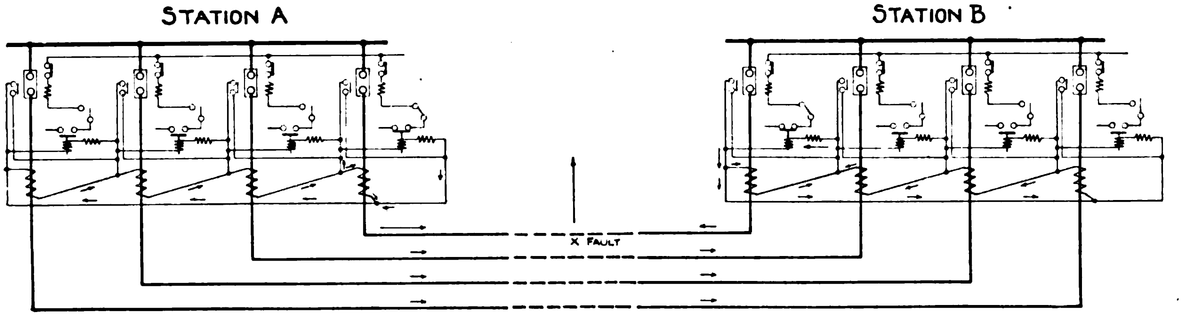


FIG. 13—BALANCED PROTECTION FOR THREE OR MORE PARALLEL LINES (DISCRIMINATING)

and potential connections to the directional relay should be so made that for power flowing from the bus to the line the contacts would close on the side to trip the breaker of the line in service. When both lines are working, the circuit having the greater flow of power from the bus to the line will control the operation of the Directional relay and, therefore, trip the breaker of the line in trouble which always carries the greater power from the bus to the line.

It should be borne in mind that power flowing from the line to the bus is of negative value, therefore, for cases such as shown in Fig. 10, where power flows from the line to station B bus over both circuits, the circuit having the greater flow from bus to line is the one having the least flow from line to bus.

In the event of one line being in service alone, it is the general practise automatically, by means of auxiliary switches on the circuit breakers, to introduce time, over-current relays in the protective equipment which will operate in conjunction with the Directional relays in a manner similar to that described in connection with Fig. 4 or Fig. 5 (Tandem groups or loop circuits). This time delay also serves to prevent the opening of the sound line immediately following the tripping of the faulty one. In place of the single directional relay with double throw contact, it is also possible to obtain substantially the same results with two sets of relays with single throw contacts arranged in a manner similar to that described for the protection of three or more parallel lines and shown in Fig. 12.

Balanced Protection for Three or More Parallel Lines. (Discriminating). Where a number of parallel lines are involved the underlying feature is the same as described in connection with Fig. 9, although the treatment of the matter is necessarily different. Here, as shown in Fig. 12, the current transformer secondaries are connected all in series in a loop circuit so that, when the primary currents are all equal the secondary currents will also be equal and will circulate through the loop as one current of the magnitude of each, and practically none will pass through the coils of the over-current and directional relays which are connected across each current transformer secondary.

Fig. 13 illustrates a fault in one line such that power is reversed at station B in this line from the direction taken by the remaining sound lines. It will be observed that only in the case of the injured line is the power direction through the directional relays (as indicated by the arrows) such that the contacts will close. At station A this is because there is a preponderance of positive power flowing from the bus into this particular line. At station B the injured line is the only one having positive outward flowing power.

Inasmuch as the success of the scheme depends upon the relatively low impedance of the loop circuit as compared to the impedance of the coils, it will be apparent that some method should be provided to eliminate the useless impedance injected in the loop circuit by the relays of a dead feeder. This is usually done automatically by short circuiting, by means of auxiliary switches on the circuit breakers or by auxiliary relays controlled by such auxiliary switches, the relay equipment of the line whose circuit breaker is open.

It will be noted that when all but one line is out of service, the relay equipment of this last line will be short circuited by the auxiliary switches or relays referred to in the preceding paragraph and accordingly the last line will be non-automatic unless some means is provided to open the loop circuit. This opening of the loop may be accomplished manually or it may be done automatically with considerable complication of auxiliary switches, etc., which complication is usually considered inadvisable. When the loop has been opened, each feeder will be left with over-current and directional protection at values determined by the settings of the over-current relays. Various other, also somewhat complicated, means may be used for inserting additional relays for the protection of this last line which on account of their variety will not be described here.

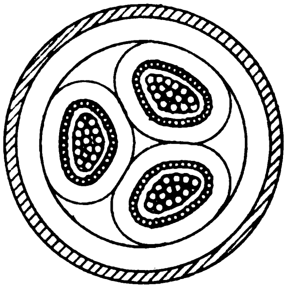
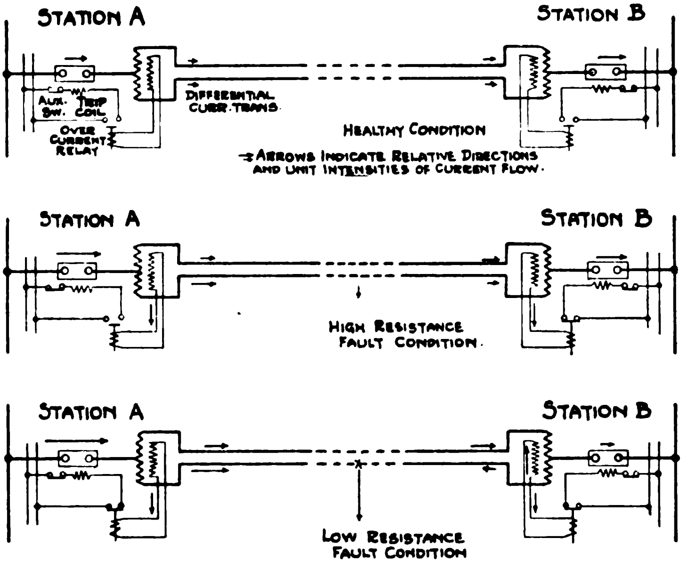


FIG. 14

If an open circuit should occur in one of the conductors or if, when putting another line into service only the breaker at one end is closed, an unbalanced condition will result which may tend to open the good lines in use if the current flowing at the time, is sufficiently great. This danger becomes relatively smaller as the number of lines involved is increased because the secondary unbalancing will be inversely proportional to the number of lines in service. For instance, if the over-current relays are set to operate at the normal load of each feeder and if four lines are in, (3 continuous and one open at one point) an overload of three times normal on each feeder would be required before any trouble could be encountered.

One installation of this scheme is described in a paper by Mr. Philip Torchio, "Relays for High Tension Lines," TRANS. A. I. E. E., Vol. XXXVI, page 361, March 1917.

Split Conductor Protection. Split conductor cables are being tried out in this country by two operating companies who report good results to date. The cable is comprised of six conductors, each of the three phases being "split" into two halves. A section of the cable used is shown in Fig. 14.


STATION A
STATION B
AUX. SW.
TRIP COIL
OVER CURRENT RELAY
DIFFERENTIAL CURR. TRANS.
HEALTHY CONDITION
ARROWS INDICATE RELATIVE DIRECTIONS AND UNIT INTENSITIES OF CURRENT FLOW.
STATION A
STATION B
HIGH RESISTANCE FAULT CONDITION.
STATION A
STATION B
LOW RESISTANCE FAULT CONDITION

FIGS. 15, 16 AND 17—SPLIT-CONDUCTOR SYSTEM PROTECTION

The healthy and faulty conditions are illustrated in Figs. 15, 16 and 17. The action of the relays is similar to that described in connection with the two-parallel-line equipment shown in Figs. 7 and 8, excepting that under end fault conditions, additional devices (such as are described in the paper referred to in the next paragraph) are required to provide the necessary unbalancing. Repetition here will therefore be unnecessary.

The above greatly curtailed description is intended to cover in a simple way the underlying principle of split conductor protection. For more specific information the reader is referred to the paper by Mr. W. H. Cole, "Split Conductor

Cables—Balanced Protection," PROCEEDINGS A. I. E. E., July 1918, page 793.

Pilot Wire System with Balanced Pressures. Adaptations of the Merz-Price protective system have been used by two operating companies. One of these reports very satisfactory results, the other is not so favorable due to an inherent difficulty in obtaining the proper degree of balance.

Fig. 18 illustrates the scheme of connections. The current transformers in each end of the circuit have their secondaries connected in opposition so that when current flows through the feeder, a potential is produced across each current transformer secondary. As these pressures, at the two ends of the line, are produced by equal currents passing through similar transformers they also will be equal and, being in opposition, no current will flow.

If, however, the input to the cable exceeds its output the corresponding potentials across the transformers will become unbalanced and a current will pass through the pilot wires and, at the same time, through the relays connected in series at each end. The operation of these relays serves to trip the circuit breakers.

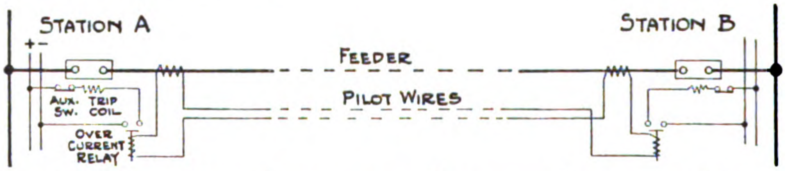


Fig. 18—Pilot Wire System with Balanced Pressures—Merz-Price System

A modification of this method of protection is illustrated in the paper by R. F. Schuchardt: "Protective Relays" TRANS. A. I. E. E., Vol. XXXVI, page 383, 1917.

COMBINATION OF UNDER-VOLTAGE AND OVER-CURRENT RELAYS FOR PROTECTING TRANSMISSION LINES

One of the companies reported an application of a combination of under-voltage and over-current relays for their system which has given them very satisfactory results.

In this scheme all the circuit breakers in any section are mechanically locked in the closed position by means of a magnetically operated lock. It is controlled by a voltage relay which releases the lock when the voltage falls below a predetermined value (approximately 70 per cent). Upon the occurrence of a short circuit the voltage drops and when it has fallen below the predetermined point the voltage relays act to unlock the circuit breakers which are then free to be opened by the over-current relay or other over-current device. Thus, in most cases, only the breakers in the affected section can open on short circuit. It sometimes happens, however, that when two stations are close together, breakers in an unaffected section may be unlocked but usually the over-current device will act to open the proper ones only and clear the trouble before the others can operate.

Referring to the diagram Fig. 19 the under-voltage relays are connected to the secondaries of potential transformers on the line buses. An auxiliary relay is actuated from the station service transformer and is controlled by the under-voltage relays. In its turn this auxiliary relay controls the locks on the circuit breakers. One set of under-voltage relays, with the auxiliary relay, may control a number of locks on a number of circuit breakers. The operation is as follows:

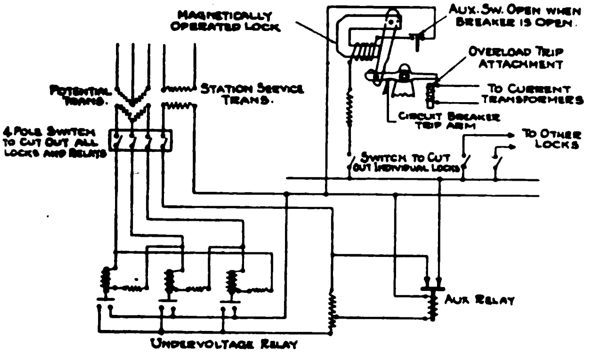


FIG. 19—UNDERVOLTAGE AND OVERCURRENT RELAY—SCHEME OF CONNECTIONS

When the line potential drops below a predetermined value, one or more of the under-voltage relays drop and short circuit the auxiliary relay through a resistance which causes this auxiliary relay to open. This, in turn, releases the latch and leaves all the circuit breakers under its control free to operate in case of over-current. Thus, so long as the potential remains above the predetermined value, no breaker can be opened by its automatic over-current feature.

This scheme, illustrated in Fig. 19, is reported as giving successful results on an over-head system covering 4000 square miles where there is a large number of stations located on an average of approximately 10 miles apart. As the lowest voltage occurs nearest the short circuit, it is probable that only the circuit breakers in the immediate vicinity will be unlocked and allow the circuit breakers to be automatically opened if the current is of sufficient magnitude.

APPENDIX

In reply to a general questionnaire which was sent out to sixty-one operating companies, information was received from thirty-two giving analysis of their relay protective schemes, from which the following summary was made.

Of the companies reporting, about 60 per cent cover supply systems for the larger cities and the remaining 40 per cent cover widely distributed territories of a number of smaller cities in which cases there are in general a number of water power stations.

Ques. 1. *a.—How often do you check current and time settings on your relays?*

Ans.—From the general reports submitted from central stations it seems to be the general practise to make a periodic check on the current and time settings of the relays.

Of the companies reporting, 70 per cent make this periodic check and the average complete check for each relay is once every three months; 27 per cent make no periodic check but most of them report making checks after cases of trouble and at intervals depending on operating conditions; 3 per cent report that they make no check whatever on the relay system.

Ques. 1 *b.—Have you a regular routine for making tests and inspection; What is it?*

Ans.—Approximately 70 per cent of the operating companies reporting have a regular routine of making tests.

Although the reports are not very definite, some of the larger companies have found it desirable to disconnect the circuit from service and test the relays by applying the testing circuit to the current transformer secondary terminals with the complete relay circuit left intact so that current transformer is left in shunt with the relay circuit under test. This method is found to give more accurate test results under varying conditions of various loads, relay circuits and different types of current transformers.

A few of the companies make their tests on the relays with the feeder alive which necessitates disconnecting the trip circuits and for the period of test the feeder circuit breakers are left non-automatic. This test may be made at relay terminals or at current transformer terminals in which case a check is made of the wiring.

Ques. 1. c.—*Do you calibrate with a stop watch, or do you use some other instrument? What is it?*

Ans.—For good relay calibration it is apparently becoming the practise to use some form of an automatic chronometer or cycle-counter in which the personal equation of the tester is eliminated. Of the companies reporting, 63 per cent have adopted this method of calibration where 37 per cent still hold to the old form of the stop watch.

Ques. 1. d.—*Do you make a more frequent inspection for dust and dirt and mechanical defects? At what intervals?*

Ans.—Of the reporting companies 65 per cent make a more frequent inspection of the relays for dust, dirt and mechanical defects and these additional inspections vary from periods of one week to one month.

Ques. 2. a.—*Do you test and adjust relays with the current according to the setting or to the current that will probably flow at the time of short circuit?*

Ans.—There is a growing tendency to test the relays with currents approximating the short circuit conditions as borne out by the fact that 50 per cent of the operating companies reporting are now testing under these conditions. The results obtained by these companies show that this method is a marked improvement over the earlier method of small currents.

Ques. 2. b.—*In adjusting relays for selective operation how do you determine the current and time settings of the several relays?*

Ans.—With companies, where the testing is made approximating short-circuit conditions, the settings are arrived at in general from the determinations of the short-circuit conditions and the relays on which selective operation is desired are set to give selectivity under these conditions with allowances made in time settings for the actual operation of circuit breakers, the minimum time being determined by the estimated requirements for preventing operation on system load and surges.

In some companies the settings are determined by a "trial process" which is the result of the actual operations obtained under trouble conditions. Others use either the calculating table (See *G E Review*, October 1916), or Mathematical Calculations—See *G. E. Review*, June 1916 and *Electrical Journal*, July 1916) for determining these conditions while others report the advisability of installing recording instruments for determining these conditions in a purely practical manner.

Ques. 2. c.—*In determining the current settings of your relays do you consider the probable short-circuit current with all generators in operation or with reduced generating capacity such as corresponds to the average or minimum load?*

Ans.—Of the operating companies reporting their settings determined by short-circuit conditions, 62 per cent determine their settings with the minimum generating capacity and in addition some of these consider also the maximum generating conditions, and 25 per cent consider only the maximum generating conditions, 13 per cent consider the average generating conditions.

Ques. 3. *a & b.—Do you use a-c. or d-c. for tripping oil circuit breakers on transmission lines? Is it satisfactory?*

Ans.—Of the replying companies 80 per cent use d-c. tripping current and most of them find it satisfactory and preferable and of the 20 per cent that use a-c. current only in one case did they state that they believed the a-c. to be preferable.

Storage batteries, and in some cases primary batteries, have been used for giving direct current for tripping.

Some of the central stations have had trouble with their circuit-breaker control circuits when connected to the d-c. excitation bus, due to the surges produced on the excitation system in cases of heavy short circuits on the high tension system.

Ques. 4—*Do you connect watthour meters or indicating wattmeters to the same current transformers as your relays?*

Ans.—In 30 per cent of the cases neither watthour nor indicating wattmeters are connected to the same current transformers as the relays.

In 35 per cent of the systems the relays are connected to the meters in cases where a high degree of meter accuracy is not required.

In 35 per cent of the systems, the relays are connected with the meters with no restrictions mentioned.

Ques. 5—*Do you attempt to operate underground or overhead transmission lines with a ground on one phase, and if so, for how long before disconnecting?*

Ans.—Of the systems answering the questionnaire 67 per cent are grounded and the ground line is automatically disconnected.

Of the remaining systems, which are ungrounded, 25 per cent operate for short intervals (no longer than necessary and in no case longer than 30 minutes) with a ground on one line and 75 per cent disconnect the grounded line immediately.

Ques. 6.—*What is the longest time (in seconds) as determined by your relay settings and switch constants, that a short circuit is permitted to exist on your transmission lines before the switch is opened automatically?*

Ans.—The average maximum time as reported from the operating companies on which a short circuit is kept on the system is $3^1/_3$seconds. This time varies with different companies from ¼ of a second to as high as 15 seconds.

We wish to point out that the above is not the time on which the heaviest short circuit is held on the system which cases are undoubtedly much shorter than given above. In some cases where the longer time is permitted, there has been trouble experienced due to synchronous apparatus falling out of step. Two seconds is apparently a good limit for heavy short circuits.

Ques. 7.—*About what percentage of your transmission line troubles are ground and what percentage are short circuits between phases?*

Ans.—Of the systems reporting, an average of 70 per cent of the troubles are started from ground. There is considerable variation in the reports; for example, some give as high as 90 per cent to ground while others give as low as 25 per cent to ground. We feel this discrepancy is probably due to the fact that some of the operating companies have no records to show what portion of the trouble did actually start from the ground.

Ques. 8.—*Do you ordinarily keep all transmission lines in service or do you keep some lines dead and in reserve?*

Ans.—Of the operating companies reporting 93 per cent keep all of their good transmission lines in service without any held in reserve with the exception of two cases where with overhead high voltage transmission lines one of two parallel lines is taken out of service for reserve during lightning disturbances and in one of these cases the line is grounded at this time.

Ques. 9.—*Where you have several schemes of relay protection that accomplish practically the same purpose, will you kindly state your preference and your reasons?*

Ans.—Of the companies reporting 13 per cent prefer the combination of time current and directional relay schemes, 13 per cent the balanced pair, 6 per cent split conductor, 6 per cent straight inverse time current protection, and 3 per cent balanced relay with pilot wires.

And of the remaining systems there was only one relay scheme in operation from which no comparison could be drawn.

Ques. 10.—*Have you any scheme of relay protection which in your opinion is particularly effective for your conditions? If so will you kindly state in some detail the desirable features of this system?*

Ans.—Of the companies reporting, 32 per cent feel that some form of a balanced relay protection is well adapted for their conditions. Of this 32 per cent, 6½ per cent prefer the split conductor scheme, 6½ per cent, two lines operated as a unit with balanced overload protection: 16 per cent, two lines in multiple with the balanced directional and current relays for disconnecting a single defective line only; and 3 per cent use pilot wires.

22 per cent find that the current-directional relay combination gives particularly good results for their conditions and some of these find that the connection of the potential circuits of the directional relay to the substation bus side of transformers, where not in parallel on high-tension side, give preferable operating conditions, as a higher voltage is maintained under short circuit conditions.

3 per cent find special ground relays desirable (Refer to A. I. E. E. TRANSACTIONS p. 361 vol. 26).

6 per cent prefer definite time limit relays as they have given very satisfactory service.

3 per cent prefer no automatic protection on very high-tension lines.

3 per cent find that a combination current and under voltage relay system has solved, for their conditions, difficulties that they have not been able to overcome with any other scheme.

Balance report no special conditions.

Ques. 11—*Have you some installations or schemes of operation for which you find difficulty in securing a satisfactory scheme of relay protection? If so, please describe?*

Ans.—Several companies reported that they have had difficulty in finding a proper relay protection in cases where they have taps on the tie lines between stations. This is particularly true where the protection of these lines would have been of the balanced relay type were it not for the taps.

Other companies at present using the balanced current relay protection, which automatically disconnects both feeders in case of trouble on either, on parallel lines would like to find a simple relay scheme which would disconnect only the damaged line of the pair in case of trouble on one of the lines.

Some difficulty has also been experienced in finding the proper relay protection for tie lines between stations where very heavy momentary surges may exist with the flow of power in either direction without any actual trouble on the tie lines themselves.

Large variations in generating equipment, in operation with water power systems, caused the operating companies difficulty in finding a relay arrangement which would provide protection under all these different conditions.

Ques. 12.—*Do you attempt to operate all of your transmission lines in parallel by groups? Or in parallel?*

Ans.—Of the companies reporting 60 per cent operate with the major part of their lines in parallel and 40 per cent operate with some of their lines in parallel by groups and in some other cases the lines are strictly radial.

Ques. 13—*Have you in operation a balanced relay system with pilot wires?*

94 per cent of the companies reporting use no balanced relay system with pilot wires. In one instance it was reported that pilot wire scheme had been tried out but its use discontinued.

Ques. 14 *a. b. & c.*—*Do you use a balanced relay scheme consisting of split conductor cable or lines in multiple?*

When trouble occurs on one line of two in multiple is the good line again placed in service while repairing the other line?

What protective scheme do you have on the single line during the repairs on the line in trouble?

Ans.—72 per cent of the reports indicate that no balanced scheme of any kind is used.

6 per cent use split conductor protection of the six conductor cable type.

3 per cent use a similar scheme excepting that the six conductors comprise two separate three-phase circuits. For this scheme it was reported that after the two lines had been disconnected, due to a fault in one, the good line was found by test and put back in service as quickly as possible with inverse-time limit protection at each end.

19 per cent report other schemes of balanced protection with directional relays in which selective isolation of the injured line is attempted.

Ques. 15 *a. b. & c.—What are the principal difficulties that you have experienced with relay protective system?*

Have you experienced any false operations or failures of relays to operate?

Have you been able to attribute such difficulties to defects in the relay, the design of the relay protective system, the difficulties in making proper connections, or to the irregular operation of oil circuit breakers? Please answer in some detail?

Ans.—Practically all the companies report trouble with the operation of their protective relay system. Of these troubles there are 46 per cent reported due to the difficulties in the relay, 20 per cent to improper application of the relays, 15 per cent to improper settings of the relays, 9 per cent to defective wiring, and 10 per cent to defective operation of the oil circuit breakers.

Several of the companies reporting trouble with the relays find that they were due to the chattering of the bellows type of relay in which cases some of the trouble had been eliminated by replacing this relay with other time current types and in some cases it was eliminated by the installation of a saturating reactor in shunt with the relays. The shunt reactor eliminated the trouble and gave a desirable characteristic time curve at a considerably lower cost than required to replace the relays.

Some defective operations of directional relays are reported, in most cases of which the relays were of the old type.

Some companies report a change in calibration with time and although these cases are not very explicit, the trouble could probably be avoided by a more frequent check and inspection of the relay.

Of the troubles due to improper wiring, some of these are attributed to a wrong connection of the potential element of directional relays and some to a wrong connection of the balanced or differentially connected relays and the remainder is due to poor workmanship.

Ques. 16—*What is the maximum current that can flow into a short circuit on a transmission line just outside the generating station?*

a. The maximum instantaneous current?

b. The maximum sustained current?

Ans.—Report covers the experience from thirty-one operating companies with systems varying from 25,000 to 455,000 kv-a. whose short circuit currents, at any point, vary in value from 100,000 to 1,650,000 kv-a. and sustained short circuit kv-a. values vary from 20,000 to 340,000 kv-a.

GENERATING STATION DATA

Of the systems reporting, 67 per cent operate with the grounded neutral. Of these 40 per cent are grounded without resistance, 23 per cent grounded through low resistance and 4 per cent are grounded through a high resistance where special ground relays are required for selective operation on grounds.

TIE LINE RELAY PROTECTION

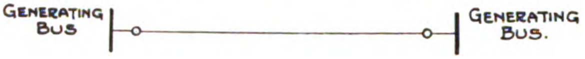


DIAGRAM A

About one-third of the companies reporting had tie lines that could be classified under this connection. Of these—

55 per cent of the lines were protected by means of inverse time current relays only.

5 per cent use balanced protection with pilot wires.

5 per cent use split conductor installations.

35 per cent were provided with directional and current relay protection.

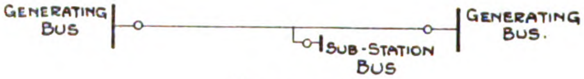


DIAGRAM B

About one-fifth of the companies reporting had tie lines that could be classified under this connection. Of these—

85 per cent of the lines reported were provided with inverse time current relays only.

15 per cent were provided with current and directional protection.

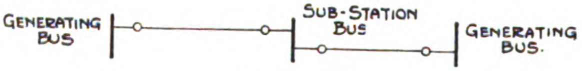


DIAGRAM C

About one-fourth of the companies reporting had tie lines that were classified under this connection. Of these—

50 per cent of the lines reported were protected by inverse time current relays only.

25 per cent by current and directional relays.

10 per cent were provided with balanced protection using pilot wires.

15 per cent were provided with balanced pair protection.

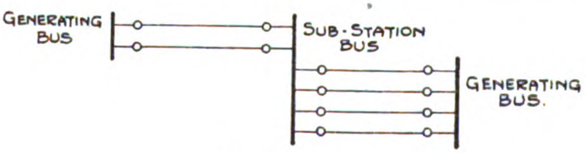


DIAGRAM D

About one-tenth of the companies reporting had tie lines that were classified under this connection. Of these—

65 per cent of the lines reported were protected by means of inverse time current relays.

35 per cent were equipped with current and directional relays.

TRANSMISSION LINE RELAY PROTECTION

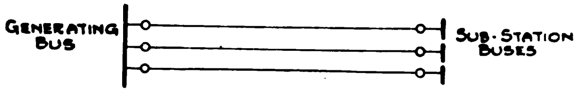


DIAGRAM E

About one-eighth of the reporting companies have lines that were classified under this type. Of these—

75 per cent of the lines were protected by inverse-time current relays.

25 per cent of the lines were protected by directional relays and current relays.

(Even on a radial system the secondary connections of the step-down transformers may be in parallel and cause a feed back in case of trouble which makes a directional relay desirable.

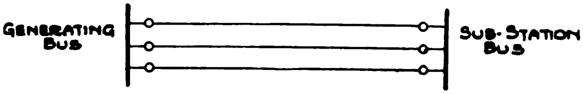


DIAGRAM F

About one-half of the companies have lines in this classification. Of these—

40 per cent of the lines were reported to have current and directional protection.

55 per cent were equipped with inverse-time current relays only.

5 per cent were protected by balanced relays of the interconnected directional type.

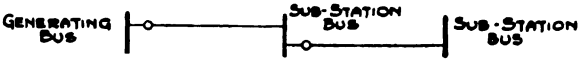


DIAGRAM G

About one-tenth of the companies have lines under this classification of which one-half are protected by inverse-time current relays and one-half by balanced connections.

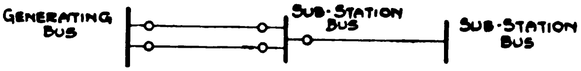


DIAGRAM H

About two-fifths of the companies have lines under this classification. Of these—

55 per cent were reported to have inverse-time current relay protection.

30 per cent were equipped with directional and current protection.

7½ per cent were equipped with balanced relay protection with pilot wires.

7½ per cent were equipped with balanced relay protection scheme using directional relays.

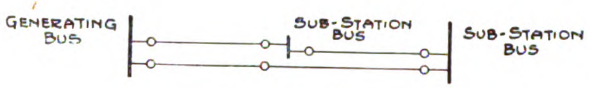


DIAGRAM I

About one-eighth of the companies have line classifications in this list. Of these—

75 per cent were reported to be protected by means of current relays and directional relays.

25 per cent by means of inverse-time current relays only.

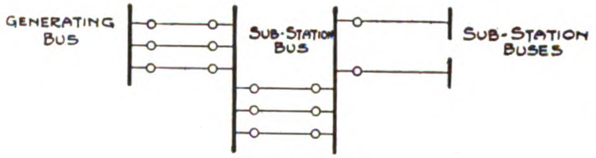


DIAGRAM J

Two companies reported lines in this classification and in both cases straight inverse-time current relay protection was used.

To be presented at the 35th Annual Convention of the American Institute of Electrical Engineers, Lake Placid Club, N. Y., June 24, 1919.

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(*Subject to final revision for the Transactions.*)

HIGH-TENSION SINGLE-CONDUCTOR CABLE FOR POLYPHASE SYSTEMS

BY W. S. CLARK AND G. B. SHANKLIN

ABSTRACT OF PAPER

Three-conductor underground cable is limited to a line potential of about 25,000 or 30,000 volts. The transmission and distribution of large amounts of power at this voltage involves heavy investment in copper.

The only factor that limits the voltage rating of single-conductor sheathed cable is over-all diameter. Line voltages of 44,000 and 55,000 volts are perfectly practical and mean a saving in copper over three-conductor cable of as much as 70 per cent. Induced sheath voltage or current, depending upon whether sheath is open- or short-circuited, is the only factor in the operation of single-conductor cable that needs serious consideration.

In this paper the dielectric, inductive and general line characteristics of three-conductor and single-conductor cable are compared. The advantages and disadvantages of each type of cable are brought out in a way that will aid in deciding the merits of individual problems.

INTRODUCTION

SINGLE-CONDUCTOR sheathed cable has been used only to a limited extent for conducting polyphase energy. This has been but a natural result of conditions. Multi-conductor cable has generally met underground service conditions satisfactorily and there has been a sufficient overlap with overhead high-tension service to make one of the two meet all but a very few exceptional cases.

Single-conductor cable is more economical than multi-conductor only when there are large quantities of high-tension power to be handled. It is only within recent years that steadily increasing units of power have reached figures that make the substitution of single conductor cable for multi-conductor an attractive proposition.

Another feature favorable (although not welcome from an economical standpoint) to a more extended use of high tension single-conductor cable is the tendency towards abolishment of overhead lines in densely populated districts.

Manuscript of this paper was received April 29, 1919.

COMPARISON OF MULTI-CONDUCTOR AND SINGLE-CONDUCTOR CABLE

The use of multi-conductor cable for transmitting and distributing large amounts of power economically is limited in two ways; by the maximum allowable voltage, and conductor cross section, or current carrying capacity.

The highest operating voltage in ducts is about 30 kv. This voltage will probably never be safely exceeded to much of an extent in ordinary three conductor cable, because of the tangential stresses first pointed out by Höchstadter.[1]

Conductor cross section is limited to about 250,000 or 300,000 circular mils. Larger conductors than this would make the cable unwieldy, difficult to manufacture, transport and install. The radius to which it could be safely bent would not be small enough for installation purposes. For a rise of 30 deg. cent. a 300,000-cir. mil, 30 kv., three-conductor cable will carry approximately 230 amperes per conductor under favorable conditions. This represents 12,000 kv-a. per cable. The copper loss will be 6.54 watts per duct-ft. per cable at 55 deg. cent. With 12/32-in. by 6/32-in. thickness of insulation and 9/64-in. lead sheath the outer diameter is 3.63 in. Since this is the highest voltage and largest cross section that it is practical to use we may regard this design as having the least amount of copper and lowest I^2R losses for the given amount of power to be transmitted.

Now, let us compare this limiting size of three-conductor cable with different designs of single-conductor cable. Comparison is best made by reference to the design data in Table I. Cable (a) is the three-conductor cable discussed above. Cable (b) is single-conductor cable, has the same voltage to neutral as (a) and the same total copper cross section, also the same current density. The kv-a. capacity and copper loss per duct-ft. are therefore the same. The two must be distinguished between however, as (a) is a separate three-phase circuit, while (b) is only one leg of a three-phase circuit. It is assumed that the total amount of power to be transmitted will require three cables or some multiple of three, of either type and the cables will each be in separate ducts. It is then easy to see how closely the conditions coincide.

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[1] "Three Core Cables" E. T. Z. Heft. 47, 1915. Abstract in *London Electrician*, 1916, p. 209.

TABLE I

COMPARISON OF THREE-CONDUCTOR AND SINGLE-CONDUCTOR CABLE THREE-PHASE Y CONNECTION

Cable	Total copper cross section cm.	Core diam. in.	Cond. diam. in.	Thick. insul. in.	Lead sheath in	Overall diam. in.	3 ϕ volt to neut. Kv.	Current per cable	Kv-a. capacity per cable	$I^2 R$ loss per ft. per cable watts	Ratio a/b	Kv/.cm. G_{max}
					Three conductor cable.							
(a)	3 x 300,000	0	0.631	12/32x6/32	9/64	3.63	$30/\sqrt{3}$	3 x 231	12,000	3 x 2.18	......	......
					Single conductor cable.							
(b)	900,000	0	1.09	17/32	1/8	2.40	$30/\sqrt{3}$	693	12,000	6.54	0.505	18.3
(c)	275,000	1.16	1.30	1 3/32	9/64	3.76	$55/\sqrt{3}$	378	12,000	6.32	0.370	19.5
(d)	550,000	1.00	1.30	1 3/32	9/64	3.76	$55/\sqrt{3}$	378	12,000	3.00	0.370	19.5

An advantage of (b) over (a) is in its smaller over-all diameter. The cost of installation would be less, especially as regards simplicity of joints, and the cable itself would be cheaper because of less insulation and lead. Another advantage is that (b) can be more safely overloaded with less danger of deterioration developing, as there are no tangential stresses.

The disadvantages of single-conductor cable depend upon individual cases and involve rather complicated considerations such as: transposition at manholes, necessity of breaking the continuity of lead sheath or accepting the additional loss introduced by short circuited sheath. This will be dealt with later in a way that will aid in deciding the merits of each individual case.

We would not especially recommend the substitution of cable (b) for (a) although there probably are cases, such as short tie-ins, where it would be advantageous. The real advantage of single conductor cable lies in the opportunity for much higher operating voltage with consequent reduction in copper cross section and increase in line efficiency.

Cable (c) is designed to transmit at $55/\sqrt{3}$ kv. the same amount of power as (a) and (b) with the same loss per duct ft. There is, therefore, no gain in line efficiency, but the amount of copper has been reduced to less than one-third of that needed in (b).

If the limiting feature is line loss rather than investment in copper the copper cross section can be increased until the proper blaance is reached. In cable (d) the copper cross section is doubled and the I^2R loss thereby even more than halved because of the lower operating temperature. Cable (c) is designed to operate at 55 deg. cent. and (d) at about 37 deg. cent., 12,000 kv-a.

Liberal copper cross section is a good investment in any cable and particularly so in this type, for the additional cost involved is solely that of the bulk copper, which can be realized upon when the cable is scrapped. Reference to the design data of (c) and (d) will show what is meant by this. They both have exactly the same conductor diameter, which is fixed by the voltage rating and not by the amount of copper. The conductor is filled out to this diameter by wrapping the strands over a core, usually made of hemp rope. The only dimension that is different in (c) and (d) is the diameter of this core. Obviously, (d) is good for 41 per cent overload in an emergency.

Cable (d) with only 550,000 cir. mils of copper can transmit 41 per cent more load than (b), which has 900,000 cir. mils copper, for the same temperature rise.

DESIGN OF SINGLE CONDUCTOR CABLE

The most important point to be considered in designing a high-tension cable is the maximum voltage stress. In a recent paper[2] a method of determining the maximum allowable stress is worked out in detail. For paper cable impregnated with mineral hydro-carbon base compound the maximum working stress is placed at between 19 and 20 kv-eff. per cm. (48.3 and 50.8 volts per mil.) The formula for calculating the maximum stress in single conductor cable is

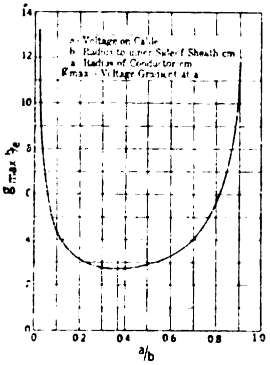

FIG. 1—SHOWING THE MOST EFFICIENT CROSS SECTION OF SINGLE-CONDUCTOR CABLE

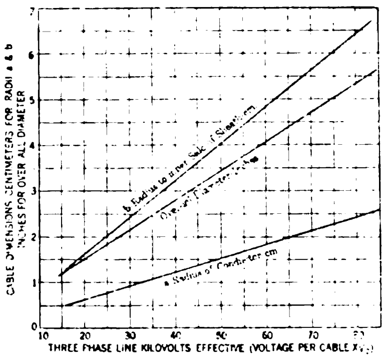

FIG. 2—SINGLE-CONDUCTOR CABLE—SMALLEST OVER-ALL DIAMETER FOR GIVEN VALUE OF G_{max}

G_{max} . = 19.5 kv./cm.

$b/a = \epsilon = 2.718$

$$g_{max} = \frac{e}{a \log_\epsilon b/a}$$

where

e = impressed voltage.

a = radius of conductor in cm.

b = radius to inner side of sheath in cm.

A curve is given in Fig. 1, calculated with the above formula and assuming different values of the ratio a/b. The most efficient cross section of cable, that is, the smallest cross section for any given conditions, is determined from the minimum ordinate of this curve. Ratio a/b found in this way has a value of 0.370, or b/a is exactly equal to the naperian logarithm base, $\epsilon = 2.718$.

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[2] "Ionization of Occluded Gases in High Tension Insulation," by G. B. Shanklin and J. J. Matson. PROC. A. I. E. E., Feb. 1919.

A safe working stress is selected at 19.5 kv. per cm. (49.5 volts/mil.) With $a/b = 0.370$ the most efficient dimensions of cable are calculated at various voltage ratings and are given as curves in Fig. 2.

Cable (b) in Table I, has a conductor diameter that cannot be reduced to the most efficient value because of the large cross section of copper involved. The "skin effect" is rather high,—7 per cent at 60 cycles. If this were a low-voltage cable it would be well to use a cored conductor to reduce "skin effect." There is an interesting relation between "skin effect" loss and dielectric loss in different cross sections of high voltage cable, whereby, one is so nearly neutralized by the other as to allow considerable lee-way in designs. Space will not allow us to deal with this feature. It is mentioned here simply as an explanation of why the more desirable coreless conductor is used in cable (b).

With one thirty-second in. thickness of impregnated paper, $g_{max} = 18.3$ kv. per cm. and ratio $a/b = 0.505$. Reference to Fig. 1 shows this ratio to be high. The overall diameter is 2.4 in., whereas the minimum diameter for the same voltage rating in Fig. 2 is 2.15 in. However, the over-all diameter of 2.4 in. is sufficiently small to be easily handled and any further reduction would not be of great importance. When feasible, it is better not to stress a cable up to the maximum limit of 19.5 kv. per cm. That is why cable (b) is stressed to only 18.3 kv. per cm. The factor of safety is not only greater but due to lower dielectric loss, the cable can safely operate at a higher temperature.

With higher-voltage cable, over-all diameter is of greater importance, in fact, it is the only thing that limits the voltage rating. The practical limit of over-all diameter is about 3.9 in. (9.9 cm.) at the very most. From Fig. 2 the corresponding voltage rating is $57/\sqrt{3}$ kv. Cables (c) and (d) in Table I are rated at $55/\sqrt{3}$ kv., the nearest standard voltage to this. It would not be practical to use cable rated at, say, $66/\sqrt{3}$ kv. The over-all diameter would then be 4.46 in. (11.33 cm.) With special machinery for manufacture and special means of transportation and installation it would be possible to use such cable, but the extra expense involved would hardly warrant the benefit derived.

Grading of Single Conductor Cable

It, no doubt, has occurred to the reader that since the over-all diameter is limited, further gain in voltage rating could be accomplished by grading the insulation. Osborne[3] and Beaver[4] demonstrated the advantages, from a theoretical standpoint, of graded cables. Actually, however, from a practical standpoint grading has few possibilities.

If all other factors are ignored grading is of benefit only if:

(a) there are high grade insulating materials of reasonable cost to select from, whose permittivities cover a fairly wide range, and individually have consistent values of permittivity that do not vary in different batches, or with ageing, etc.

(b) these materials have the same allowable working stress, regardless of their individual permittivities. If the allowable stress varied directly with permittivity it is apparent that even better results could be obtained by grading.

Neither of these two conditions actually hold. As far as (a) is concerned there are only three materials that can be considered, and of these three, one, rubber, introduces doubtful features. Aside from its high cost there are questions of its stability and length of life when used in composition with other materials, especially in such extremely high-voltage cable. The truth is, rubber has never been given a thorough try out in high-voltage cable because of its prohibitive cost.

The three materials mentioned and the range of their 60 cycle, relative permittivities at 55 deg. cent. are listed below:

Rubber, 4.6 to 6.0
Varnished cambric, 3.8 to 5.2
Impregnated paper, 2.8 to 4.0

A better representation of permittivity characteristics can be obtained from the dielectric loss data which will be given in this paper and those in two papers read before the Institute in 1917[5] and 1919.[2]

It is apparent from the above values that rough grading could be accomplished by using these three materials, but, condition (b) upsets this combination. In the paper, "Ionization of Occluded Gases, etc.,"[2] the safe maximum working stress for impregnated paper is placed at 19.5 kv. per cm. (49.5 volts per mil) while that for varnished cambric is only 16.0 kv. per cm. (40.6 volts per mil) because of its higher permittivity. Rubber insulation is not dealt with in that paper. We have made tests on rubber insulated cable, however, and found that its corresponding stress is a little less than that for varnished cambric, 15 kv. per cm. (38.1 volts per mil).

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[3] "Potential Stresses in Dielectrics" by H. S. Osborne, TRANS. A. I. E. E., Vol. XXIX, p. 1553.

[4] "Cables" by C. J. Beaver, *Journ. I. E. E.*, Vol. 53, 1915.

[5] "Insulation Characteristics of High Voltage Cables" by Clark and Shanklin, PROC. A. I. E. E., June, 1917,

It follows from all this, that practically no advantage is gained by an attempt to grade with these materials, because their maximum allowable working stress is inversely proportional to their relative permittivities. It is much better to have the insulation a homogeneous, compact mass of impregnated paper and aim towards a uniformly high grade product with low temperature coefficient and dielectric losses.

Beaver, in his paper on "Cables,"[4] advocates the metallic inter-sheath method of grading as furnishing means of overcoming the almost universal objections to the variable permittivity method. He proposes connecting these inter-sheaths to transformer taps and holding them at some definite, predetermined potential. As far as we know, this has never been tried out in practise, and we doubt if any operating company would be willing to assume the risk involved. The chief objections to this method are:

a. The inter-sheath must necessarily be of flimsy construction and there is danger of damaging it or even breaking its continuity during transportation and installation. High local potentials would concentrate at this point, resulting in failure.

b. The length of line would be very limited, as the inter-sheath could not carry the heavy charging current in long lines.

c. This method is based on the supposition that it is desirable to equally stress the whole insulation cross section. Actually, it is not desirable, because of the high dielectric loss involved.

d. Weak spots in the different layers would be lined up over the whole length. Failure of one layer would throw full potential on the others, also the short circuit current might fuse the inter-sheath at some point far distant from the original point of failure.

The only other way of increasing voltage rating without prohibitive increase in over-all diameter is by stressing the cable above the safe limit we have assumed of 19.5 kv. per cm. This value is just about a maximum of what popular experience has shown to be conservative practise. It is more than a coincidence that recent laboratory investigations[2] check it very closely. The only radical departure from this practice we know of has been tried in Germany. In several instances underground cables have been worked at stresses much higher than 19.5 kv. per cm.[6] Just how successfully these experiments worked out over a reasonable period of time we do not know.

The single conductor cable referred to in Litchtenstein's paper operated at a stress of 42 kv. per cm. At the time his paper was published it had operated intermittently for twenty months, however, the frequency was only 16 $^2/_3$ cycles and the current only 2.4 per cent of full-load current.

DIELECTRIC LOSSES

When estimating the watts loss in a conduit line the dielectric loss is often ignored. This is a great mistake. Even in the highest grade cable this loss is an appreciable part of the total, although, as a rule, a small part. The higher the voltage rating and operating temperature the more nearly it approaches the copper loss. In poor grade cable this loss may be even more than the copper loss. Consequently, the very highest grade of impregnated paper is absolutely necessary for high tension cable.

The amount of space that can be given to dielectric energy loss characteristics is necessarily limited in this paper for the inductive characteristics of single-conductor sheathed cable and the general line characteristics must also be dealt with. We will limit the data presented to three designs of single-conductor cable and then show an empirical method of calculating the dielectric characteristics for any cross section of cable either single- or three-conductor.

The loss measurements were taken by the "Compensated Dynamometer Wattmeter Method," which is described in detail in an article published in 1916.[7] The energy loss data given

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[6] "Underground High-Tension (60-kv.) Cables" by Leon Litchtenstein E. T. Z. Jan. 1913, Abstract in *Elec. Rev.* March 7, 1913.

"30,000 Volt, Three-Phase Cable System, Berlin" by W. Pfaunkuch, E. T. Z., April, 1916.

[7] "Compensated Dynamometer Wattmeter Method of Measuring Dielectric Energy Loss", by G. B. Shanklin, *General Electric Review*, Oct. 1916.

TABLE II.
CABLE SAMPLE NO. I.

Dia. over bare copper strands 1.186 in. (3.012 cm.).

Insulation—26/32 in. (2.064 cm.) thickness paper filled with mineral hydro-carbon base compound.

Temp.	Freq.	e kv.	i_d $\times 10^{-3}$	w_d	ρ_{av} $\times 10^{10}$	K_{av}	C $\times 10^{-10}$	$\cos\theta_d$ per cent
23 deg. cent	60	12.01	0.276	0.0219	148.3	3.11	0.610	0.660
		18.01	0.411	0.0497	147.2	3.09	0.607	0.673
		21.00	0.489	0.0671	148.0	3.14	0.616	0.654
		23.99	0.559	0.0878	147.2	3.14	0.616	0.657
		26.98	0.630	0.1118	146.8	3.15	0.619	0.657
		29.97	0.700	0.1372	147.2	3.16	0.621	0.655
		32.96	0.772	0.1959	125.0	3.17	0.623	0.758
		35.95	0.840	0.2960	98.3	3.16	0.621	0.980
		41.93	1.018	0.6790	58.3	3.28	0.645	1.592
		47.90	1.200	1.3320	38.7	3.39	0.666	2.320
61.5 deg. cent	60	12.01	0.292	0.404	8.05	3.26	0.640	11.50
		18.01	0.440	0.920	7.95	3.28	0.643	11.61
		21.00	0.513	1.258	7.90	3.28	0.643	11.70
		23.99	0.589	1.637	7.90	3.28	0.645	11.61
		26.98	0.660	2.090	7.82	3.28	0.644	11.72
		29.97	0.732	2.560	7.89	3.28	0.644	11.68
		32.96	0.807	3.100	7.82	3.28	0.645	12.01
		35.95	0.888	3.890	7.49	3.31	0.650	12.20
		41.93	1.053	5.680	6.96	3.38	0.663	12.88
		47.90	1.246	7.750	6.64	3.49	0.686	13.01
60 deg. cent	25	11.99	0.136	0.304	10.60	3.60	0.707	18.68
		17.98	0.206	0.689	10.55	3.64	0.717	18.62
		20.97	0.240	0.940	10.52	3.64	0.715	18.68
		23.97	0.273	1.211	10.64	3.64	0.714	18.50
		26.96	0.310	1.538	10.68	3.66	0.720	18.40
		29.95	0.343	1.901	10.60	3.64	0.715	18.50
		32.94	0.380	2.300	10.58	3.67	0.722	18.40
		35.92	0.414	2.790	10.42	3.66	0.720	18.80
		41.91	0.494	3.980	9.92	3.76	0.738	19.28
		47.90	0.591	5.640	9.14	3.93	0.772	19.90
100 deg. cent	60	12.01	0.333	1.300	2.50	3.56	0.700	32.45
		18.01	0.501	2.730	2.65	3.58	0.703	30.32
		21.00	0.588	3.780	2.60	3.60	0.707	30.60
		23.99	0.670	4.970	2.60	3.60	0.706	31.00
		26.98	0.769	6.12	2.65	3.67	0.721	29.55
		29.97	0.849	7.750	2.60	3.64	0.716	30.50
		32.96	0.940	9.440	2.56	3.66	0.719	30.50
		35.95	1.037	11.890	2.45	3.70	0.728	31.90
		41.93	1.250	17.650	2.24	3.80	0.747	33.80
		47.90	1.482	23.500	2.19	3.94	0.775	33.10

TABLE II. *(continued)*

Temp.	Freq.	e kv.	i_d $\times 10^{-3}$	w_d	ρ_{av} $\times 10^{10}$	K_{ar}	C $\times 10^{-10}$	$\cos\theta_d$ per cent
100 deg. cent	25	11.99	0.169	0.827	3.91	4.16	0.816	40.90
		17.98	0.254	1.880	3.89	4.17	0.820	41.30
		20.97	0.296	2.550	3.88	4.17	0.820	41.10
		23.97	0.339	3.330	3.88	4.17	0.820	41.00
		26.96	0.380	4.280	3.82	4.16	0.818	41.90
		29.95	0.422	5.190	3.88	4.17	0.820	41.00
		32.94	0.469	6.290	3.88	4.21	0.827	40.70
		35.92	0.519	7.680	3.78	4.25	0.836	41.20
		41.91	0.630	10.970	3.60	4.43	0.870	41.60
		47.90	0.753	14.980	3.44	4.65	0.911	41.50
60 deg. cent	60	12.01	0.283	0.288	11.25	3.18	0.623	8.45
		18.01	0.431	0.644	11.35	3.22	0.634	8.29
		21.00	0.509	0.875	11.35	3.27	0.642	8.20
		23.99	0.579	1.134	11.40	3.25	0.639	8.15
		26.98	0.651	1.339	11.37	3.25	0.639	8.20
		29.97	0.722	1.780	11.35	3.25	0.639	8.24
		32.96	0.801	2.245	10.89	3.28	0.645	8.52
		35.95	0.877	2.840	10.25	3.30	0.649	9.01
		41.93	1.036	4.270	9.25	3.36	0.660	9.86
		47.90	1.232	6.070	8.48	3.45	0.677	10.30
60 deg. cent	25	11.99	0.130	0.253	12.82	3.47	0.683	16.22
		17.98	0.195	0.573	12.70	3.46	0.680	16.39
		20.97	0.230	0.775	12.76	3.52	0.691	16.10
		23.97	0.263	1.011	12.76	3.51	0.691	16.05
		26.96	0.298	1.262	12.80	3.52	0.691	15.78
		29.95	0.331	1.580	12.76	3.53	0.694	15.92
		32.94	0.366	1.931	12.65	3.55	0.697	16.02
		35.92	0.402	2.330	12.45	3.58	0.704	16.12
		41.91	0.486	3.400	11.61	3.71	0.730	16.69
		47.90	0.574	4.960	10.38	3.82	0.750	18.10
23 deg. cent	60	12.01	0.281	0.0262	124.0	3.16	0.621	0.777
		18.01	0.424	0.0595	123.0	3.17	0.623	0.782
		21.00	0.495	0.0796	124.5	3.18	0.626	0.767
		23.99	0.565	0.1038	124.5	3.18	0.626	0.767
		26.98	0.640	0.1318	124.0	3.20	0.629	0.762
		29.97	0.710	0.1684	120.0	3.20	0.629	0.794
		32.96	0.780	0.2760	88.6	3.20	0.629	1.072
		35.95	0.854	0.4130	70.5	3.20	0.629	1.347
		41.93	0.995	0.8290	47.7	3.20	0.629	1.990
		47.90	1.179	1.4590	35.3	3.32	0.653	2.580

in this paper can be considered as supplemental to those in the two papers previously referred to [2] and [5] and are dealt with in the same way.

In Table II, 25- and 60-cycle data are given for a high-tension single conductor cable (No. 1) having the following specifications.

Conductor. 58 strands, each 0.104 in. diameter in two layers, on a core 0.770 in. (1.956 cm.) diameter. Total conductor diameter 1.186 in. (3.012 cm.) Cross section 625,000 cir. mils

Insulation. 26/32 in. (2.064 cm.) thickness paper filled with mineral hydro-carbon base compound.

Sheath. 0.101 in. (.257 cm.) thickness of lead.

Over-all Diam. 3.02 in. (7.67 cm.)

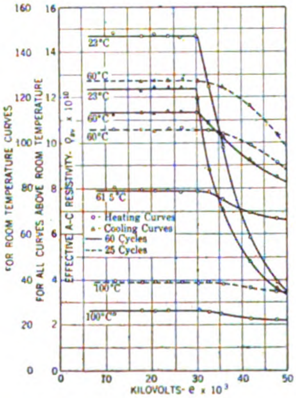


FIG. 3—CABLE NO. 1—SINGLE CONDUCTOR (SEE TABLE II)

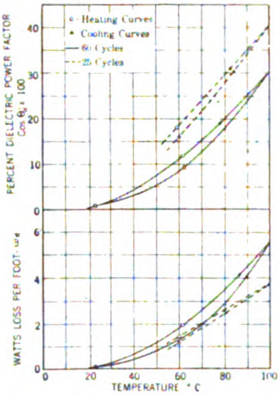


FIG. 4—CABLE NO. 1—SINGLE CONDUCTOR (SEE TABLE II) CURVES PLOTTED AT 25.4 KV.

The measurements in Table II are given consecutively in the same order in which they were taken in the laboratory. The nomenclature and the method of calculating the different values can be found in Appendix A. In Figs. 3 and 4 curves are given of effective a-c. resistivity vs. impressed voltage, watts loss per ft. vs. temperature, and dielectric power factor vs. temperature. These curves show the more important characteristics. The other characteristics may be obtained from Table II. Space does not allow the presentation of them all in the form of curves.

Referring to Fig. 3 the resistivity (ρ_{av}) is constant up to the impressed voltage at which internal ionization starts, in other words, the dielectric loss varies as the square of the voltage

TABLE III
CABLE SAMPLE NO. 2

Dia. over smooth conductor surface 1.311 in. (3.33 cm.)

Insulation—24/32 in. (1.905 cm.) thickness paper filled with mineral hydro-carbon base compound.

Temp.	Freq.	e Kv.	i_d $\times 10^{-3}$	w_d	ρ_{av} $\times 10^{10}$	K_{av}	C $\times 10^{-10}$	$\cos\theta_d$ per cent
24 deg. cent.	60	12.01	0.309	0.0196	185.2	3.06	0.679	0.527
		18.01	0.468	0.0442	184.6	3.10	0.689	0.525
		21.00	0.549	0.0603	184.0	3.11	0.692	0.524
		23.99	0.628	0.0789	184.0	3.13	0.695	0.524
		26.98	0.707	0.0996	184.0	3.14	0.697	0.523
		29.97	0.785	0.1420	159.0	3.13	0.695	0.604
		32.96	0.864	0.2218	123.2	3.13	0.695	0.779
		35.95	0.940	0.3550	91.6	3.11	0.692	1.050
		41.93	1.125	0.8900	49.7	3.21	0.714	1.890
		47.90	1.327	1.8500	31.2	3.19	0.735	2.920
60 deg. cent.	60	12.01	0.328	0.298	12.15	3.26	0.724	7.55
		18.01	0.492	0.674	12.08	3.26	0.724	7.60
		21.00	0.580	0.925	12.00	3.29	0.730	7.60
		23.99	0.660	1.211	11.95	2.28	0.730	7.64
		26.98	0.744	1.529	12.00	3.28	0.730	7.63
		29.97	0.829	1.911	12.00	3.29	0.732	7.71
		32.96	0.910	2.410	11.90	3.28	0.730	8.03
		35.95	0.990	2.940	11.05	3.27	0.726	8.26
		41.93	1.190	4.650	9.51	3.38	0.750	9.34
		47.90	1.400	6.910	8.34	3.47	0.772	10.32
60 deg. cent.	25	11.99	0.150	0.251	14.40	3.56	0.790	13.95
		17.98	0.227	0.559	14.51	3.59	0.796	13.72
		20.97	0.269	0.768	14.40	3.65	0.810	13.62
		23.97	0.304	1.006	14.35	3.60	0.798	13.96
		26.96	0.345	1.260	14.40	3.63	0.805	13.68
		29.95	0.387	1.565	14.40	3.69	0.814	13.50
		32.94	0.423	1.906	14.35	3.65	0.809	13.68
		35.92	0.464	2.304	14.09	3.66	0.814	13.90
		41.91	0.551	3.480	12.69	3.75	0.831	15.05
		47.90	0.655	5.350	10.77	3.87	0.858	17.09
100 deg. cent.	60	12.01	0.372	1.16	3.13	3.57	0.793	25.90
		18.01	0.561	2.56	3.20	3.60	0.799	25.25
		21.00	0.656	3.64	3.06	3.61	0.803	26.30
		23.99	0.746	4.63	3.13	3.60	0.799	25.80
		26.98	0.850	5.85	3.13	3.64	0.804	25.60
		29.97	0.950	7.10	3.18	3.66	0.813	25.00
		32.96	1.032	9.55	3.08	3.68	0.816	26.95
		35.95	1.173	11.79	2.81	3.74	0.831	27.90
		41.93	1.410	17.70	2.50	3.83	0.851	30.00
		47.90	1.665	25.50	2.26	3.94	0.875	32.00
100 deg. cent.	25	11.99	0.188	0.87	4.20	4.17	0.926	38.20
		17.98	0.280	1.92	4.24	4.14	0.917	38.20
		20.97	0.330	2.57	4.32	4.20	0.931	37.00
		23.97	0.379	3.37	4.28	4.21	0.935	37.20
		26.96	0.426	4.26	4.28	4.21	0.935	37.20
		29.95	0.472	5.26	4.28	4.20	0.931	37.30
		32.94	0.529	6.61	4.32	4.26	0.947	37.90
		35.92	0.579	8.09	4.01	4.25	0.944	38.90
		41.91	0.699	11.98	3.68	4.37	0.971	40.90
		47.90	0.836	16.72	3.45	4.57	1.013	41.70

TABLE III (*continued*)

Temp.	Freq.	e Kv.	i_d $\times 10^{-3}$	w_d	ρ_{av} $\times 10^{10}$	K_{av}	C $\times 10^{-10}$	$\cos \theta_d$ per cent
60 deg. cent.	60	12.01	0.318	0.219	16.60	3.15	0.700	5.72
		18.01	0.478	0.490	16.64	3.16	0.700	5.69
		21.00	0.555	0.665	16.70	3.15	0.700	5.71
		23.99	0.631	0.870	16.64	3.15	0.700	5.75
		26.98	0.719	1.101	16.64	3.17	0.704	5.70
		29.97	0.800	1.381	16.64	3.18	0.706	5.76
		32.96	0.882	1.759	16.37	3.19	0.708	6.05
		35.95	0.964	2.222	14.65	3.20	0.711	6.43
		41.93	1.156	3.690	12.00	3.29	0.729	7.64
		47.90	1.370	6.040	9.56	3.40	0.755	9.22
60 deg. cent.	25	11.99	0.147	0.190	19.00	3.49	0.774	10.81
		17.98	0.220	0.430	18.85	3.49	0.774	10.89
		20.97	0.253	0.590	18.75	3.45	0.765	11.11
		23.97	0.290	0.769	18.80	3.45	0.765	11.08
		26.96	0.330	0.973	18.80	3.50	0.775	10.93
		29.95	0.363	1.199	18.80	3.45	0.765	11.02
		32.94	0.402	1.452	18.70	3.49	0.774	10.97
		35.92	0.446	1.811	17.90	3.55	0.789	11.30
		41.91	0.532	2.879	15.36	3.63	0.804	12.90
		47.90	0.634	4.810	12.00	3.75	0.833	15.90
29 deg. cent.	60	12.01	0.301	0.0241	150.0	2.99	0.665	0.670
		18.01	0.460	0.0538	151.0	3.05	0.676	0.649
		21.00	0.539	0.0731	151.5	3.06	0.679	0.648
		23.99	0.612	0.0959	151.0	3.05	0.676	0.652
		26.98	0.701	0.1220	151.0	3.00	0.666	0.645
		29.97	0.774	0.1548	146.0	3.08	0.684	0.668
		32.96	0.859	0.2190	124.8	3.12	0.691	0.775
		35.95	0.935	0.3310	98.2	3.11	0.689	0.985
		41.93	1.118	0.7360	60.0	3.18	0.707	1.579
		47.90	1.323	1.7750	32.5	3.31	0.734	2.800
29 deg. cent.	25	11.99	0.133	0.0213	170.0	3.35	0.744	1.340
		17.98	0.209	0.0476	170.5	3.34	0.741	1.269
		20.97	0.245	0.0654	169.0	3.35	0.744	1.278
		23.97	0.274	0.0846	170.5	3.28	0.728	1.290
		26.96	0.311	0.1074	170.0	3.32	0.736	1.284
		29.95	0.350	0.1348	167.2	3.36	0.744	1.285
		32.94	0.386	0.1782	153.1	3.36	0.744	1.405
		35.92	0.416	0.2425	134.0	3.33	0.739	1.620
		41.91	0.496	0.5740	77.0	3.41	0.756	2.760
		47.90	0.590	1.2440	45.4	3.54	0.786	4.410

up to this point. From here on ionization introduces additional loss and ρ_{av} drops rapidly. The minimum voltage at which ionization starts is 30 kv. and the voltage stress at the conductor is

$$g_{max} = \frac{30}{a \log_\epsilon b/a} = 23.1 \text{ kv. per cm.}$$

Since this cable is designed to operate at $44/\sqrt{3} = 25.4$ kv., or at a voltage stress, $g_{max} = 19.5$ kv. per cm., it is apparent that there is no danger of internal ionization during operation. The divergence between the 25- and 60-cycle watts loss increases

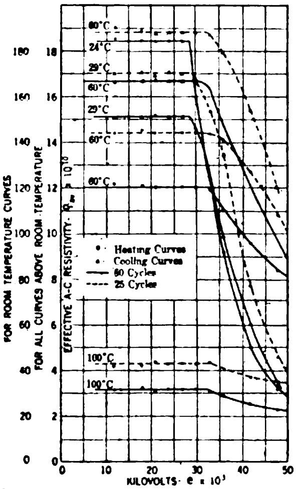


Fig. 5—Cable No. 2—Single Conductor (See Table III)

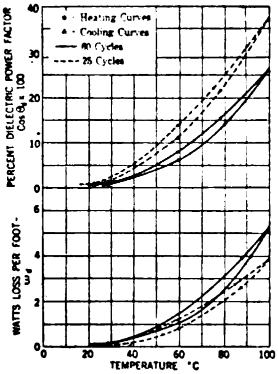


Fig. 6—Cable No. 2—Single Conductor (See Table III) Curves Plotted at 25.4 kv.

with temperature (Fig. 4). The power factor, of course, is higher at 25 cycles. No 25-cycle measurements at room temperature are given but will be for the other two cables.

In Table III measurements are given for cable No. 2, having the following specifications:

Conductor. Same as that for cable No. 1 except that a 1/16 in. (0.1578 cm.) lead jacket was placed over the bare strands to give a smooth surface. Conductor diameter 1.186 + 0.125 = 1.311 in. (3.33 cm.)

Insulation. 24/32 in. (1.905 cm.) thickness paper filled with mineral hydro-carbon base compound.

Sheath. Same as cable No. 1.

Over-all Diameter. Same as cable No. 1.

The test on this cable was made to determine by comparison with No. 1, the benefit derived from a smooth surfaced conductor. The ρ_{av} vs. E curves in Fig. 5 give a minimum ionization voltage of 28.5 kv., which corresponds to a voltage stress at the conductor, g_{max} = 22.5 kv. per cm. This is even less than the voltage stress in cable No. 1 and would indicate that there is practically no difference between stranded and smooth surfaced conductors. The watts and power factor curves in Fig. 6 show No. 2 to have slightly less loss than No. 1. This is only a variation that often occurs in different batches and has nothing to do with the type of conductor. It is due to slight differences of the compound, thoroughness of filling, and compactness of the paper wrappings.

There are two factors involved in high-tension cable that are of equally vital importance. One, high dielectric losses, has already been emphasized. The other, loosely wrapped paper and poor filling is best brought out by the measurements on a special length of cable (No. 3) given in Table IV. This cable had the following specifications:

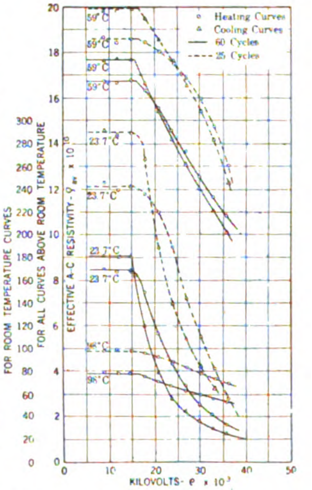


FIG. 8—LOOSE WRAPPINGS (SEE TABLE IV)

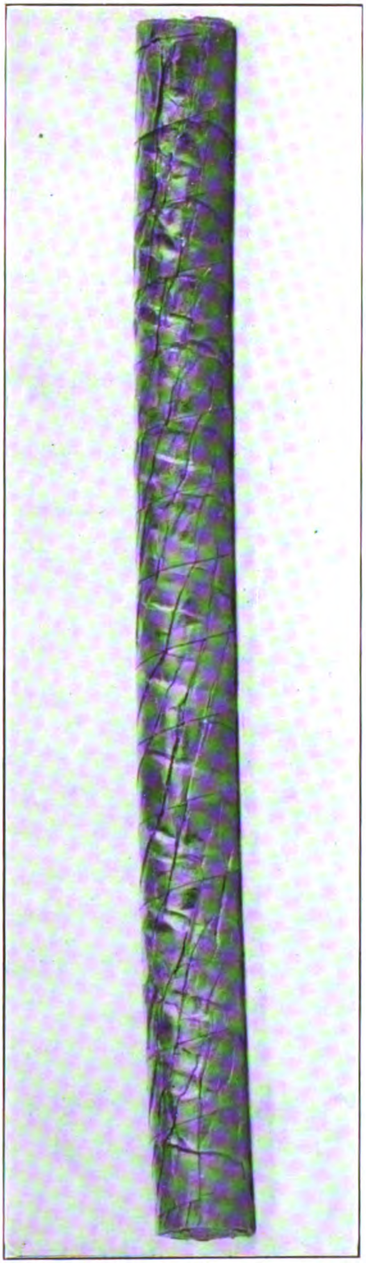
Conductor. Same as cable No. 1.

Insulation. 22/32 in. (1.746 cm.) wrapped on loosely and poorly filled with mineral hydrocarbon base compound.

Sheath. 9/64 in. (0.357 cm.) thickness of lead.

The first few wrappings of paper were loosely applied with the remaining wrappings applied in the usual way. The length was then vacuum treated and filled with compound, but not left in the compounding tank for the usual period of time. Consequently, the spaces between the loose wrinkled wrappings were not well filled. These wrinkles are plainly shown in Fig. 7, the photograph being taken after all but the first two paper wrappings were removed.

The ρ_{av} vs. E curves in Fig. 8 show decidedly more ionization than occurred in Cables Nos. 1 and 2. Ionization starts at



[Clark and Shanklin]

Fig. 7—Cable No. 3—Wrinkling of Impregnated Paper Wrapping near Conductor (Two Wrappings only Remaining)

TABLE IV.
CABLE SAMPLE NO. 3

Dia. over stranded conductor surface same as Cable No. 1.

Insulation—22/32 in. (1.746 cm.) thickness paper loosely wrapped and partly filled with mineral hydro-carbon base compound.

Temp.	Freq.	e kv.	i_d × 10^{-3}	w_d	ρ_{av} × 10^{10}	K_{av}	C × 10^{-10}	$\cos\theta_d$ per cent
23.7 deg. cent	60	9.00	0.221	0.0118	170.0	2.96	0.651	0.595
		11.99	0.296	0.0214	168.0	2.97	0.653	0.601
		14.99	0.374	0.0331	169.0	3.01	0.660	0.590
		17.98	0.449	0.0540	148.9	3.02	0.663	0.669
		20.97	0.525	0.0976	112.0	3.02	0.663	0.885
		23.95	0.599	0.1651	86.2	3.02	0.663	1.153
		26.94	0.679	0.2730	66.2	3.04	0.668	1.495
		29.93	0.760	0.4440	50.2	3.07	0.675	1.952
		32.91	0.844	0.6510	41.3	3.10	0.681	2.345
		35.90	0.925	0.9710	33.0	3.12	0.685	2.920
23.7 deg. cent	25	8.98	0.094	0.0082	246.0	3.12	0.664	0.971
		11.97	0.126	0.0148	240.0	3.16	0.671	0.981
		14.97	0.158	0.0230	242.0	3.16	0.671	0.976
		17.98	0.191	0.0342	235.0	3.18	0.675	0.998
		20.99	0.222	0.0499	220.0	3.16	0.671	1.074
		24.01	0.257	0.0761	188.2	3.21	0.682	1.233
		27.05	0.296	0.1270	143.2	3.28	0.697	1.585
		30.11	0.342	0.2030	111.0	3.40	0.723	1.978
		33.21	0.401	0.3340	82.0	3.62	0.770	2.505
		36.34	0.498	0.5870	56.0	4.11	0.874	3.240
59 deg. cent	60	9.00	0.228	0.120-	16.72	3.05	0.670	5.86
		11.99	0.306	0.216	16.60	3.08	0.676	5.86
		14.99	0.385	0.334	16.72	3.09	0.679	5.80
		17.98	0.461	0.492	16.32	3.09	0.679	5.94
		20.97	0.540	0.705	15.51	3.10	0.681	6.22
		23.95	0.620	0.979	14.56	3.12	0.685	6.58
		26.94	0.702	1.328	13.62	3.14	0.690	7.01
		29.93	0.785	1.770	12.56	3.16	0.695	7.54
		32.91	0.871	2.307	11.64	3.18	0.700	8.03
		35.90	0.960	2.958	10.83	3.22	0.709	8.57
59 deg. cent	25	8.98	0.098	0.107	18.65	3.26	0.693	12.20
		11.97	0.132	0.193	18.45	3.29	0.700	12.10
		14.97	0.165	0.301	18.56	3.28	0.696	12.20
		17.98	0.199	0.436	18.42	3.29	0.700	12.21
		20.99	0.234	0.609	18.05	3.30	0.704	12.42
		24.01	0.271	0.815	17.54	3.36	0.714	12.50
		27.05	0.313	1.078	16.88	3.43	0.730	12.72
		30.11	0.363	1.416	15.91	3.58	0.763	12.95
		33.21	0.421	1.859	14.74	3.76	0.799	13.28
		36.34	0.529	2.518	13.05	4.20	0.894	13.10
98 deg. cent	60	9.00	0.240	0.514	3.92	3.12	0.686	23.80
		11.99	0.321	0.924	3.87	3.13	0.688	24.00
		14.99	0.405	1.441	3.87	3.16	0.695	23.60
		17.98	0.489	2.150	3.74	3.19	0.700	24.45
		20.97	0.575	3.110	3.52	3.20	0.704	25.60
		23.95	0.662	4.260	3.34	3.22	0.707	26.90
		26.94	0.754	5.710	3.17	3.24	0.711	28.16
		29.93	0.852	7.530	2.96	3.29	0.724	29.50
		32.91	0.952	9.710	2.77	3.32	0.729	31.00
		35.90	1.047	12.340	2.62	3.32	0.729	32.80

TABLE IV. *(continued)*

Temp.	Freq.	e kv.	i_d $\times 10^{-3}$	w_d	ρ_{av} $\times 10^{10}$	K_{av}	C $\times 10^{-10}$	$\cos\theta_d$ per cent
98 deg. cent	25	8.98	0.118	0.415	4.84	3.62	0.770	39.20
		11.97	0.160	0.722	4.93	3.70	0.786	37.60
		14.97	0.199	1.149	4.84	3.66	0.780	38.50
		17.98	0.242	1.684	4.77	3.73	0.794	38.70
		20.99	0.289	2.410	4.56	3.79	0.805	39.80
		24.01	0.334	3.270	4.37	3.81	0.809	40.75
		27.05	0.386	4.440	4.10	3.87	0.823	42.50
		30.11	0.445	5.770	3.90	3.99	0.849	43.10
		33.21	0.514	7.440	3.68	4.17	0.887	43.60
		36.34	0.623	9.650	3.41	4.65	0.987	42.60
59 deg. cent	60	9.00	0.226	0.115	17.60	3.02	0.664	5.64
		11.99	0.299	0.202	17.76	3.01	0.661	5.63
		14.99	0.376	0.317	17.67	3.02	0.664	5.64
		17.98	0.454	0.484	16.61	3.04	0.668	5.94
		20.97	0.529	0.711	15.40	3.04	0.668	6.44
		23.95	0.609	1.008	14.14	3.06	0.674	6.91
		26.94	0.690	1.380	13.10	3.09	0.679	7.43
		29.93	0.773	1.851	12.03	3.11	0.684	8.00
		32.91	0.859	2.430	11.05	3.15	0.692	8.60
		35.90	0.951	3.180	10.10	3.19	0.701	9.31
59.5 deg. cent	25	8.98	0.096	0.102	18.85	3.18	0.676	11.78
		11.97	0.130	0.178	20.00	3.23	0.686	11.40
		14.97	0.163	0.280	19.95	3.24	0.688	11.48
		17.98	0.195	0.413	19.47	3.24	0.688	11.78
		20.99	0.229	0.591	18.52	3.24	0.688	12.88
		24.01	0.265	0.814	17.61	3.27	0.695	12.82
		27.05	0.308	1.100	16.54	3.38	0.718	13.21
		30.11	0.355	1.461	15.40	3.50	0.744	13.68
		33.21	0.420	1.931	14.20	3.75	0.797	13.84
		36.34	0.521	2.680	12.27	4.26	0.905	14.14
23.7 deg. cent	60	9.00	0.215	0.111	181.0	2.87	0.631	0.574
		11.99	0.288	0.198	180.2	2.91	0.639	0.574
		14.99	0.360	0.310	180.2	2.90	0.637	0.574
		17.98	0.435	0.674	119.4	2.92	0.641	0.862
		20.97	0.509	1.389	78.8	2.93	0.643	1.304
		23.95	0.586	2.542	56.0	2.96	0.651	1.811
		26.94	0.669	4.110	44.0	2.99	0.658	2.280
		29.93	0.750	6.250	35.6	3.03	0.666	2.780
		32.91	0.830	9.190	29.2	3.05	0.670	3.360
		35.90	0.921	12.900	24.8	3.10	0.682	3.900
23.7 deg. cent	25	8.98	0.092	0.0070	291.0	3.06	0.649	0.840
		11.97	0.124	0.0124	288.0	3.10	0.659	0.835
		14.97	0.155	0.0193	289.5	3.10	0.659	0.830
		17.98	0.187	0.0302	266.0	3.12	0.663	0.900
		20.99	0.219	0.0581	189.0	3.12	0.663	1.268
		24.01	0.252	0.1024	139.8	3.15	0.668	1.690
		27.05	0.292	0.1661	109.5	3.24	0.688	2.100
		30.11	0.336	0.2718	83.0	3.34	0.710	2.685
		33.21	0.400	0.4230	64.8	3.61	0.767	3.190

a minimum voltage of 15 kv., which corresponds to a stress at the conductor, $g_{max} =$ 12.95 kv. per cm. Since the cable is supposed to operate at 19.5 kv. per cm. it is evident that it would soon give trouble. The thickness of gas space estimated for this sample in the paper on internal ionization previously referred to[2] was found to be seven times that in average good cable. It is interesting to note that at voltages below ionization the watts loss per cm.[3] and the power factors are lower than those in the better cables (Nos. 1 and 2). The permittivity is also lower. This is caused by poor filling and gas spaces, since no loss is experienced in the entrapped gases. A cable made up of unfilled paper would have even less loss if well dried and provided the voltage was below ionization. This characteristic is often deceptive. The watts loss, alone, does not indicate the grade of material, unless there is reasonable assurance that it is compact and well filled.

PREDETERMINATION OF DIELECTRIC LOSS

Dielectric loss characteristics (up to the voltage at which ionization starts) can be predetermined for any cross section of cable with a fair degree of accuracy, provided sufficient measurements are available on cables made of the same materials and by the same process to obtain a good average of the dielectric power factor and permittivity. The loss variation in different batches of well made cable is not over 25 per cent which allows a difference of 12.5 per cent one way or the other from the estimated average loss.

Sixty- and 25-cycle curves of power factor and permittivity vs. temperature, for both single- and three-conductor paper cable filled with mineral hydro-carbon base compound, are given in Figs. 9 and 10. To be on the safe side, the power factor curves given are actually 10 per cent higher than the averages of a large number of tests. They are what might be termed "high average" curves. It will be noticed that the power factor is about 10 per cent higher for three-conductor cable than for single-conductor. We believe that this difference is due to the jute filler rather than three-phase stress, for we have been unable to detect any difference between the three-phase loss calculated from single-phase measurements on three-conductor cable, as described in a previous paper[5] and that actually measured with three phase voltage.

The permittivity of three conductor cable is also higher.

The jute filler doubtless has something to do with this. The greater part of the difference, however, we believe to be due to error in the approximate formulas (6 and 7 in Appendix A) used in calculating K_{av} from the measured values of c_1 and c_4 This error cancels itself out when K_{av} is converted back again to c_1 and c_4, as it must be in preliminary calculations, and is therefore of no importance. Knowing the power factor and permittivity, the loss and all other dielectric characteristics in any cross section of cable can be estimated from the formulas in Appendix A.

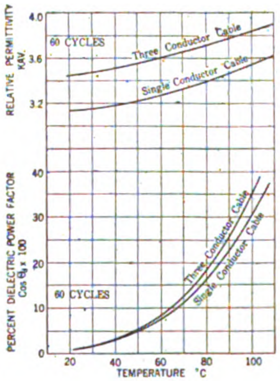


FIG. 9—PAPER CABLE FILLED WITH MINERAL HYDRO-CARBON BASE COMPOUND

These curves are 10 per cent higher than average found from large numbers of tests on different batches—they apply at all voltages below internal ionization

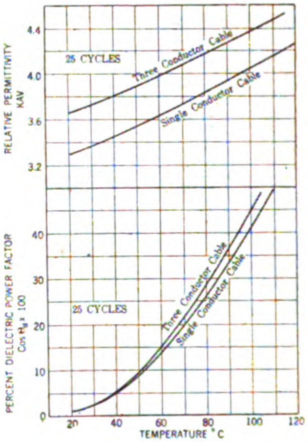


FIG. 10—PAPER CABLE FILLED WITH MINERAL HYDRO-CARBON BASE COMPOUND

These curves correspond to the 60-cycle curves in Fig. 9

INDUCTIVE CHARACTERISTICS OF SINGLE-CONDUCTOR CABLE

Dielectric characteristics are essentially functions of line voltage, and inductive characteristics of line current. The induced sheath current when sheath is short circuited, or induced voltage when open-circuited, brings in a complication in dealing with which we had considerable trouble during the initial stages of the work with single-conductor cable.

The formulas for calculating the inductive characteristics developed in Appendix B give very accurate results. In fact, the accuracy reached is greater than can be obtained by actual measurements, even when these are taken with extreme care.

The formulas are completely developed theoretically without approximations. Berg,[8] in dealing with the same subject gave short approximate formulas, but they apply only within certain limits not met with by the cable cross sections and spacings considered in this paper.

The theoretical work in Appendix B was checked in the laboratory. A number of tests were made with which we can deal only briefly. Fig. 11 gives a diagram of the test circuit. The two parallel lengths of cable were each 50 ft. in length, laid out straight on wooden horses $3\frac{1}{2}$ ft. high. The horses were made without iron nails and there was no iron within their height of the cables. A uniform magnetic field resulted. A flexible loop of cable connected the far ends of the conductors and the ends of the sheaths were bonded by a straight conductor of low resistance perpendicular to the cable lengths (a switch was inserted in the sheath bond so that external resistance could be added to the sheath circuit when desired). By extending the flexible loop out far enough its inductive effect on the sheath bond was eliminated. The drop leads were connected as shown, with corresponding pairs twisted together and arranged to reduce inductive effect to a minimum.

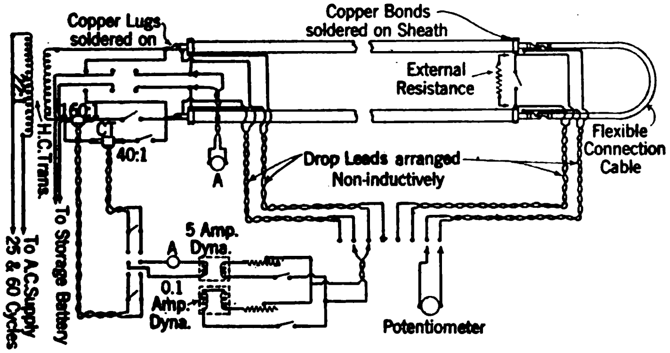


FIG. 11—CONNECTION DIAGRAM OF HIGH-CURRENT SINGLE-CONDUCTOR CABLE TEST

Current transformers stepped the current down for ammeter and wattmeter readings. Watts were read with a dynamometer wattmeter having a constant of 0.27×10^{-6}. Another very sensitive dynamometer (constant 0.013×10^{-6}) was used as a voltmeter. Induced sheath current and wattmeter current were read with carefully calibrated portable ammeters. By a double-throw switch arrangement either a-c. or d-c. readings could be taken, the d-c. voltage drop being measured with a potentiometer. The accuracy of d-c. resistance readings was greatly facilitated by the opportunity to check readings of the total circuit against the sum of the different sections.

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[8] "Constants of Cables and Magnetic Conductors" by E. J. Berg, TRANS. A. I. E. E., Vol. 26, p. 555.

The general procedure was first to measure the d-c. resistance for determination of copper and sheath temperatures. Then a-c. readings of current, watts and voltage drop were taken over a range of current that would give seven-point curves. The conductor readings were taken on the total circuit (two cable lengths plus connecting loop at far end) and then on the flexible connecting loop only, which is subtracted out. The induced sheath voltage, or current, depending upon whether open- or closed-circuited, was also measured. Finally, the d-c. resistance measurements were repeated, to make sure that no change in temperature had taken place.

The a-c. readings were taken over a fairly wide range of current. It was found that watts varied exactly as the square of the current, and voltage drop directly with the current. In other words, the line constants, such as effective resistance and inductance, were independent of current density, provided of course, there was no change in temperature. This would be expected from theoretical considerations and it is fortunate that it is so, for it allows accurate and complete calculations of line characteristics as will be shown later.

There are two sources of error in this method of test;

a. phase-angle errors, due to inductance in the current transformer and wattmeter circuit.

b. distorted wave shape.

The power factors at which the measurements were taken were fairly high. In the worst case the phase-angle error introduced was only about 4 per cent. By measurement of the current transformer phase angle and inductance of wattmeter circuit it could be largely corrected for. This source of error can be considered negligible when proper care is taken. Errors from distorted wave shape are much more difficult to overcome. The only way they can be corrected for is by using a perfect sine wave of current, which is difficult of attainment with such high values of current. Our wave shape was of the ordinary commercial type. Errors in the measurements given in the following tables were due to variances from a sine wave.

TABLE VI.—CABLE NO. 2 (See Table III.)
ALL VALUES PER 1000 FT. OF ONE CONDUCTOR TO NEUTRAL.
SHEATHS CLOSED CIRCUITED (GROUNDED IN TWO PLACES.)

Temp deg. cent.		Inches spacing D	Freq.	Measured d-c. resistance			r_c	r_{eff}		$L_{eff} \times 10^{-3}$		Z_{eff}		Ratio I_s/I_c	
Cond.	Sheath			Sheath	r_s	Cond.		Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.
26.0	26.0	24.0	60	0.1161	0.1835	0.017295	0.01736	0.03950	0.03736	0.2140	0.2155	0.0899	0.0895	0.330	0.3305
25.0	25.0	24.0	60	0.1160	1.5990	0.017210	0.01731	0.02123	0.01987	0.2383	0.2340	0.0925	0.0904	0.0415	0.0401
27.0	27.0	24.0	25	0.1146	0.1869	0.01738	0.01738	0.02180	0.02102	0.2242	0.2290	0.0411	0.0405	0.1455	0.1415
25.0	25.0	24.0	25	0.1153	1.9560	0.01727	0.01727	0.01759	0.01736	0.2378	0.2341	0.0412	0.0408	0.01395	0.01364
26.0	26.0	6.15	60	0.1150	0.1951	0.01728	0.01738	0.02390	0.02278	0.1480	0.1490	0.0606	0.0606	0.1710	0.1669
25.0	25.0	6.15	60	0.1140	1.981	0.01724	0.01734	0.01881	0.01789	0.1531	0.1508	0.0608	0.0596	0.01725	0.01665
22.0	22.0	6.15	25	0.1150	0.5890	0.01699	0.01699	0.01807	0.01731	0.1512	0.1509	0.0289	0.0293	0.02255	0.0232
23.0	23.0	6.15	25	0.1146	1.937	0.01705	0.01706	0.01751	0.01716	0.1510	0.1509	0.0295	0.0292	0.00735	0.00706

SHEATHS OPEN CIRCUITED (GROUNDED IN ONE PLACE ONLY.)

Temp. deg. cent.		Inches spacing D	Freq.	r_{d-c}	r_c		$L_{eff} \times 10^{-3}$		$M \times 10^{-3}$		Z_{eff}		Ratio e_s/E	
Cond	Sheath				Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.
27.4	26.7	24.00	60	0.01738	0.01790	0.01746	0.2398	0.2341	0.1759	0.1701	0.0921	0.08995	0.720	0.714
24.6	24.7	24.00	25	0.01718	0.01741	0.01718	0.2382	0.2341	0.1737	0.1701	0.04115	0.04055	0.658	0.657
24.0	24.0	6.15	60	0.01714	0.01784	0.01722	0.1539	0.1509	0.0899	0.0869	0.0607	0.05950	0.560	0.552
23.3	23.7	6.15	25	0.01710	0.01730	0.01710	0.1518	0.1509	0.0895	0.0869	0.02947	0.02920	0.476	0.467

A comparison between measured and calculated values of resistance and inductance for two different cross sections of cables No. 3 and 2 are given in Tables V and VI. The method of calculation and nomenclature are in Appendix B. Before the various characteristics can be calculated the resistances of the sheath and conductor must be known for any assumed temperature. These are given in Fig. 12 for the cable considered in Table V. A 12-ft. length of the cable was placed in an electric oven and d-c. measurements taken of conductor and sheath resistance over the temperature range indicated. Ignoring the spirality effect of the strands the resistance of the conductor is closely represented by copper of 98 per cent conductivity. This value of conductivity is used in Formula 4, Appendix B, for calculating the 25- and 60-cycle effective resistances r_c as given in Fig. 12.

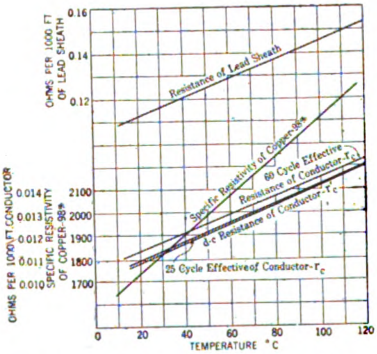

Fig. 12—D-C. and A-C. Resistance of Conductor and Sheath at Various Temperatures for Cable No. 3 (Table V)

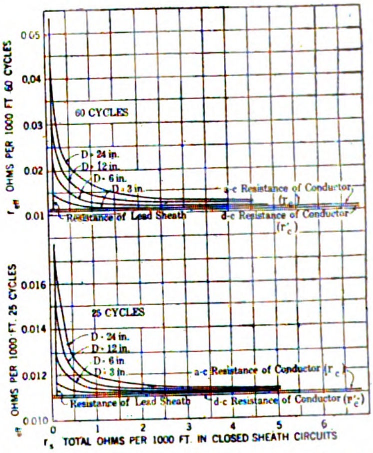

Fig. 13—Relation between Effective Resistance and Total Resistance of Closed Sheath Circuit—One Cable to Grounded Neutral (Table V) 25 Deg. Cent.

The calculated values of effective resistance r_{eff} and effective inductance L_{eff} in Table V for cable No. 3 are given in the form of curves in Figs. 13, 14 and 15. Before plotting the curves the temperature was corrected to 25 deg. cent. from Fig. 12 and by Formulas 2 and 3, Appendix B.

The curves of r_{eff} vs. r_s in Fig. 13 are very interesting. They

Copper area 1,007,000 cm.
Dia. of hemp core....... 0.594 in. (1.51 cm.)
Dia. of copper............ 1.346 in. (3.42 cm.)

Thick. of insulation....... 0.437 in. (1.11 cm.)
Thick. of sheath.......... 0.125 in. (0.3175 cm.)
Over-all dia.............. 2.47 in. (6.275 cm.)

TABLE V. (CABLE NO. 3)

VALUES GIVEN PER 1,000 FT. OF ONE CONDUCTOR TO NEUTRAL

Sheaths Closed-Circuited (Grounded in Two Places.)

Temp. deg. cent.		Spacing inches		Measured d-c. resistance			r_c		r_{eff}		$L_{eff} \times 10^{-3}$		Z_{eff}		Ratio I_s/I_c	
Cond.	Sheath	D	Freq.	Sheath	r_s	Cond.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.
26	26	24	60	0.1150	0.1455	0.01103	0.01130	0.01152	0.03930	0.03857	0.1858	0.1960	0.07955	0.08310	0.4290	0.4310
25	25	24	60	0.1145	0.7575	0.01100	......	0.01150	......	0.01780	......	0.2285	.....	0.08800	.....	0.0912
25	25	24	60	0.1145	1.3400	0.01100	......	0.01150	......	0.01508	......	0.2295	......	0.08800	......	0.0518
23	26	24	60	0.1150	1.9050	0.01091	0.01113	0.01135	0.01225	0.01393	0.2340	0.2300	0.08810	0.08800	0.03840	0.0370
25	25	24	60	0.1145	3.6550	0.01100	0.01128	0.01150	0.01245	0.01282	0.2280	0.2300	0.08470	0.08800	0.01860	0.0190
28	28	24	25	0.1158	0.1465	0.01112	0.01115	0.01121	0.01738	0.01667	0.2190	0.2225	0.03900	0.03880	0.2060	0.1935
25	25	24	25	0.1145	0.7575	0.01100	......	0.01110	......	0.01210	......	0.2300	......	0.03815	......	0.0381
25	25	24	25	0.1145	1.3400	0.01100	......	0.01110	......	0.01173	......	0.2300	......	0.03800	......	0.0216
25	25	24	25	0.1145	1.9050	0.01100	......	0.01110	......	0.01154	......	0.2300	......	0.03795	......	0.01512
25	25	24	25	0.1145	5.0000	0.01100	0.01102	0.01110	0.01129	0.01127	0.2215	0.2300	0.03690	0.03780	0.00532	0.00579
25	27	12	60	0.1153	0.1455	0.01100	0.01125	0.01150	0.02865	0.02885	0.1690	0.1710	0.06895	0.07050	0.3460	0.3480
25	25	12	60	0.1145	0.7575	0.01100	......	0.01150	......	0.01526	....	0.1876	......	0.07205	......	0.0665
25	25	12	60	0.1145	1.3400	0.01100	......	0.01150	......	0.01364	......	0.1877	......	0.07205	......	0.0381
23	25.5	12	60	0.1148	1.9050	0.01091	0.01120	0.01141	0.01255	0.01291	0.1935	0.1880	0.07195	0.07205	0.02780	0.0281
25	25	12	60	0.1145	3.6550	0.01100	......	0.01150	......	0.01228	......	0.1879	......	0.07205	......	0.01461
27	27	12	25	0.1153	0.1520	0.01109	0.01120	0.01119	0.01440	0.01437	0.1835	0.1840	0.03250	0.03175	0.1470	0.1450
25	25	12	25	0.1145	0.7575	0.01100	......	0.01110	......	0.01175	......	0.1879	......	0.03176	......	0.0290
25	25	12	25	0.1145	1.3400	0.01100	......	0.01110	......	0.01147	......	0.1879	......	0.03165	......	0.01662
25	25	12	25	0.1145	1.9050	0.01100	......	0.01110	......	0.01136	......	0.1879	......	0.03155	......	0.01170
25	25	12	25	0.1145	5.0000	0.01100	......	0.01110	......	0.01120	......	0.1879	......	0.03150	......	0.00446
23	26	6	60	0.1150	0.1455	0.01091	0.01118	0.01141	0.02115	0.02080	0.1360	0.1393	0.05660	0.05625	0.2630	0.2500
25	28	6	60	0.1158	0.7575	0.01100	0.01120	0.01150	0.01295	0.01337	0.1470	0.1455	0.05625	0.05635	0.0483	0.0496
25	27	6	60	0.1153	1.3400	0.01100	0.01125	0.01150	0.01190	0.01186	0.1430	0.1455	0.05510	0.05610	0.0224	0.0228
25	28	6	60	0.1158	2.2500	0.01100	0.01120	0.01150	0.01175	0.01172	0.1460	0.1455	0.05625	0.05600	0.0157	0.0167
25	25	6	60	0.1145	5.0500	0.01100	0.01125	0.01150	0.01154	0.01163	0.1455	0.1455	0.05600	0.05600	0.00715	0.00744
24	27	6	25	0.1154	0.1625	0.01095	0.01100	0.01105	0.01250	0.01255	0.1455	0.1450	0.02575	0.02605	0.0960	0.0951
25	25	6	25	0.1145	0.7575	0.01100	......	0.01100	......	0.01143	......	0.1455	......	0.02605	......	0.0207
25	25	6	25	0.1145	1.3400	0.01100	......	0.01100	......	0.01129	......	0.1455	......	0.02600	......	0.0117
25	25	6	25	0.1145	1.9050	0.01100	......	0.01100	......	0.01123	......	0.1455	......	0.02600	......	0.00823
25	25	6	25	0.1145	12.9750	0.01100	0.01102	0.01100	0.01110	0.01112	0.1440	0.1455	0.02520	0.02595	0.00122	0.00121
23	24	3.024	60	0.1140	0.1530	0.01091	0.01120	0.01141	0.01465	0.01446	0.1013	0.1028	0.04045	0.04115	0.1390	0.1412
25	25	3.024	60	0.1145	0.7575	0.01100	......	0.01150	......	0.01213	......	0.1040	......	0.04095	......	0.0288
25	25	3.024	60	0.1145	1.3400	0.01100	......	0.01150	......	0.01161	......	0.1040	......	0.04090	......	0.0163
24	26.5	3.024	60	0.1152	2.2500	0.01095	0.01122	0.01145	0.01155	0.01160	0.1025	0.1040	0.04025	0.04085	0.00980	0.00969
25	25	3.024	60	0.1145	3.6550	0.01100	......	0.01150	......	0.01159	......	0.1040	......	0.04085	......	0.00599
23	23	3.024	25	0.1138	0.1610	0.01091	0.01095	0.01101	0.01153	0.01154	0.1045	0.1040	0.01960	0.01985	0.0570	0.0564
25	25	3.024	25	0.1145	0.7575	0.01100	......	0.01110	......	0.01121	......	0.1040	......	0.01980	......	0.0120
25	25	3.024	25	0.1145	1.3400	0.01100	......	0.01110	......	0.01116	......	0.1040	......	0.01975	......	0.00678
25	25	3.024	25	0.1145	1.9050	0.01100	......	0.01110	......	0.01115	......	0.1040	......	0.01975	......	0.00476
25	25	3.024	25	0.1145	5.0000	0.01100	......	0.01110	......	0.01113	......	0.1040	......	0.01975	......	0.00182

Sheaths Open-Circuited (Grounded in One Place Only.)

Deg. cent. temp.	Inches spacing D	Freq.	$r_{d\text{-}c}$ meas	r_c		Inductance $L_{eff} \times 10^{-3}$		Inductance $M \times 10^{-3}$		Impedance Z_{eff}		Ratio e_s/E	
				Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.
25	24	60	0.0110	0.01125	0.01150	0.2275	0.2295	0.1825	0.1840	0.0840	0.0872	0.798	0.800
25	24	25	0.0110	0.01105	0.01110	0.2330	0.2295	0.1813	0.1840	0.0380	0.0378	0.750	0.765
25	12	60	0.0110	0.01115	0.01150	0.1908	0.1880	0.1395	0.1418	0.0715	0.0717	0.729	0.745
25	12	25	0.0110	0.01105	0.01110	0.1940	0.1880	0.1450	0.1418	0.0320	0.0316	0.712	0.705
25	6	60	0.0110	0.01120	0.01150	0.1470	0.1455	0.1010	0.0999	0.0565	0.0560	0.683	0.672
25	6	25	0.0110	0.01100	0.01110	0.1485	0.1455	0.1015	0.0999	0.0254	0.0254	0.629	0.617
25	3.024	60	0.0110	0.01120	0.01150	0.1035	0.1040	0.0563	0.0577	0.0406	0.0408	0.524	0.533
25	3.024	25	0.0110	0.01105	0.01110	0.1080	0.1040	0.0565	0.0577	0.0194	0.0198	0.457	0.466

show that at 60 cycles and a spacing between cable centers of 6 in. (15.2 cm.), which is close to the usual spacing in ducts, a resistance equal approximately to ten times that of the lead sheath must be inserted in the ground bonds to reduce the effective resistance with closed sheath circuit to within 10 per cent of that with open sheath circuit. At 25 cycles the same percentage is almost reached without any resistance at all in the sheath bonds, that is, with the sheath directly grounded. Two interesting conclusions are drawn from this:

a. In a 60-cycle line of the above cable it is better to break the continuity of the sheath into relatively short lengths (at every man hole or every other man hole) and directly ground each sheath length only once because of the high loss with short circuited sheath. This can be conveniently done by having a common neutral wire running the length of the conduit line. The continuity of the sheaths can be broken by a well designed, moisture-proof sleeve unit. Such a unit could easily be turned out in quantity production and would take the place of the ordinary jointing sleeve. This method would be better than using a continuous sheath and grounding it in two or more places through a bond resistance. Nothing is gained and a good deal is lost by grounding through bond resistance. The resistance would absorb over 90 per cent of the induced sheath voltage and the sheath would remain at almost the same potential above ground as it does open circuited. Also, such a high resistance ground is not reliable and does not afford sufficient protection.

b. 25-cycle operation is more favorable to single-conductor cable than 60-cycle. In a 25-cycle line there is the choice of either grounding the sheaths direct, which amounts to the same thing as short circuiting them, or breaking their continuity and grounding each length only once as described above. With short circuited sheaths an additional loss of 14 per cent is introduced in cable No. 3. There will be no potential between sheaths under this condition, as the sheaths, themselves, absorb the induced voltage and remain at ground potential over their whole length. If this additional loss is undesirable the continuity can be broken and the induced sheath voltage, being proportional to the frequency, will be only 42 per cent of that at 60 cycles.

The idea, of course, in breaking the continuity of the sheaths is to keep the maximum sheath voltage within reasonable limits, so that leakage, especially in wet or flooded systems, will not give trouble. Just what would constitute a reasonable limit of sheath voltage depends upon the leakage resistance between sheaths and this depends upon the particular conditions and type of conduit and manhole construction used.

As each cable is enclosed in a separate duct the leakage between sheaths over the conduit length is negligible compared with the leakage at manholes, when well constructed tile or fibre conduit is used. It is at the manholes, then, that the greatest care must be taken to reduce leakage. The ducts should spread as they project into the manhole and the sheaths well protected. The usual methods of protection used to reduce fire risk at manholes as described by Carlton[9] should prove sufficient with a little additional care, such as applying a coating of waterproof paint to the bare sheaths before the protective covering is applied. Methods of reducing sheath voltage and leakage will be dealt with further under another heading.

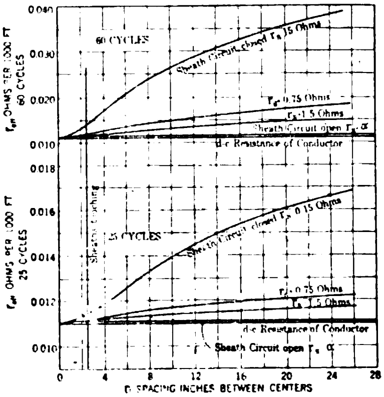

Fig. 14—25 and 60-Cycle Effective Resistance—One Cable to Neutral (Table V) 25 Deg. Cent.

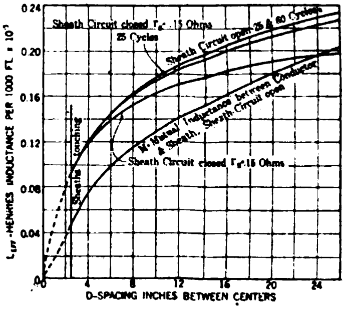

Fig. 15—Effective Inductance—One Cable to Neutral—(Table V) 25 Deg. Cent.

The effective resistance and effective inductance curves of cable No. 3 in Figs. 14 and 15 indicate clearly the importance of keeping the spacing between cables down to a minimum as far as the induced voltage or current in the sheath is concerned.

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[9] "Protection of Cables from Arcs due to the Failure of Adjacent Cables" by W. G. Carlton, A. I. E. E., 1904, p. 471.

It is surprising, though, to find that the self-inductance between conductors, and therefore the line regulation, compares very favorably with that of ordinary three-conductor cable For instance, cable (c) in Table I has an inductance per conductor to neutral of 0.145×10^{-3} henrys per 1000 ft. with a spacing of 6.74 in., while the equivalent three conductor cable (a) in Table I, has a corresponding inductance of 0.113×10^{-3} henrys with only 1.38 in. spacing. Formula 8 in Appendix B was used in calculating these values. The difference in conductor cross sectional dimensions accounts for this unexpectedly close comparison.

It must not be assumed from the foregoing discussion that all single conductor cables have as severe sheath inductive effects as Cable No. 3. This cable represents an extreme case. The sheath inductive effect for any given spacing depends upon the conductor cross section and the distance between sheath and conductor, that is, thickness of insulation. The percentage increase in effective resistance when sheath is short circuited is tabulated below for three sizes of cable at a spacing of 6 inches.

Frequency	Cable No. 3	Cable No. 2	Cable (c)
25 cycles	14.4 per cent	8.8 per cent	4.5 per cent
60 cycles	96.0 per cent	48.0 per cent	22.0 per cent

These values were calculated by the method described in Appendix B and show clearly that it is perfectly feasible to operate the higher voltage cables at 25 cycles with sheaths short-circuited. Cable (c) might even have its sheath short-circuited at 60 cycles. This question will be taken up later under another heading.

SUMMARY OF SPECIAL INDUCTIVE TESTS

Several special tests other than those dealt with above were made to determine the effects of eddy currents in the open-circuited sheath and conductor, advantage of enameling the individual conductor strands and skin effect in the conductor. The results are outlined briefly:

a. By testing lengths of lead-sheathed cable and then repeating the measurements after the sheath was removed it was clearly proved that the additional loss due to eddy currents in the open-circuited sheath was too small to be detected. Cable No. 1 was the limiting design tested in this way, that is, it had the largest conductor cross section and least thickness of insulation.

b. Lengths of cable having an ordinary conductor of bare copper strands were compared with lengths made up in identically the same way, excepting that the individual copper strands were enameled. Not the slightest difference could be detected, even at the closest possible spacing, and with conductors up to 1,000,000-cir. mil cross section. This shows that eddy currents are not appreciable in ordinary bare stranded conductors. Evidently the thin oxide film that forms naturally on the surface of the strands furnished sufficient insulation to prevent cross currents.

c. The accuracy of our test methods was not great enough to allow a close check of the skin-effect formula (4) in Appendix B. As far as we are able to determine this formula holds nicely. It also checks very closely over the range needed in this work with the results obtained by Kennelly and Affel.[10]

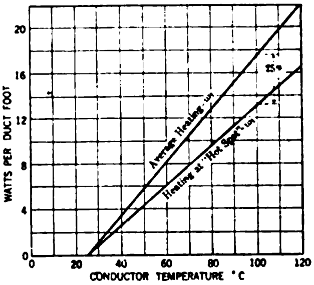

FIG. 16 — REPRESENTATIVE HEATING CHARACTERISTICS IN CONDUIT LINE—25 DEG. CENT. SURROUNDING SOIL TEMPERATURE

NOTE: The line calculations are based on these heating conditions

LINE CHARACTERISTICS OF UNDERGROUND CABLES

Heating in Underground Cable. In determining the characteristics of underground cable lines there is only one factor, the heat dissipating ability of the conduit system, that introduces serious complications. Many papers dealing with the thermal conductivity of soils and the general theory of heating in underground cables have been published, both here and abroad. They have thrown a great deal of light on the subject but it can hardly be said that any method has yet been evolved with which individual systems can be dealt with theoretically.

In calculating line efficiency, regulation, etc. the *average* heat dissipating ability of the whole length of line must be known. In determining the maximum safe load the average is of no value, the *maximum* heating at the "hot spot" section of the line must be considered instead. Fig. 16 shows the average and

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[10] "Skin Effect Resistance Measurements of Conductors" by A. E. Kennelly and H. A. Affel, *Proc. Inst. of Radio Eng.*, Dec. 1916.

"hot spot" heating characteristics for a representative conduit line, based on the assumption of 25 deg. cent. surrounding soil temperature. The curves represent a very fair average of the conditions usually met with in underground conduit. They are useful in comparing different designs of cable for line efficiency, maximum safe rating, etc.

We would recommend very strongly that some such conditions of heating be adopted as a standard. Cables could then be rated and designs compared on the basis of this standard. Without some such basis to work on it is a very uncertain matter to modify cable ratings to suit individual conduit lines, or even to suit different seasons of the year in any given line. By keeping careful temperature records under actual operating conditions and comparing them with this standard we believe that operating companies could accumulate a valuable mass of empirical data that would clear up many of the uncertainties existing to-day.

Curves similar to those in Fig. 16 can be determined for any given conduit line by a heat run, just as made on any electrical unit such as a transformer or generator. The average temperature is obtained from resistance measurements of the conductor. The maximum temperature at "hot spots" must be found by exploring temperature indicators. Since these curves are practically straight lines only one or two load readings are necessary.

We do not believe that laboratory investigations of the thermal conductivity of soils, duct walls, insulation, etc. and a mathematical study of the heat paths will ever be of practical application. This abstract method of attack has proved and will continue to be a valuable and instructive adjunct to the more direct method outlined above. We are at present conducting a laboratory investigation along these lines and hope to describe the results in a future paper.

CALCULATION OF LINE CHARACTERISTICS

The general method of calculating cable line characteristics is explained in Appendix C. It applies to relatively long lines where the effects of charging current, line regulation, etc., are appreciable. Such elaborate and complete calculations are hardly necessary in dealing with short lines, where the usual approximate methods serve the purpose.

COMPARISON OF SINGLE- AND THREE-CONDUCTOR CABLE LINES

The ultimate purpose of the cable work so far dealt with in this paper has aimed towards placing the reader in a better position to compare the relative merits of single- and three-conductor cable lines.

As a final comparison, two exactly similar four-duct conduit lines will be assumed, placed side by side and each having heating characteristics corresponding to those given in Fig. 16. Three cables of the limiting design of 30 kv. three-conductor cable, given in Table I cable (a) will be placed in one of these conduit lines. The other line will have three 55 kv. single conductor cables cable (c) designed for approximately the same loss per duct-ft. with open circuited sheath. The general line characteristics of these two limiting types of cable will be calculated and compared at 60 cycles, following the method in Appendix C. Other details will also be discussed and compared.

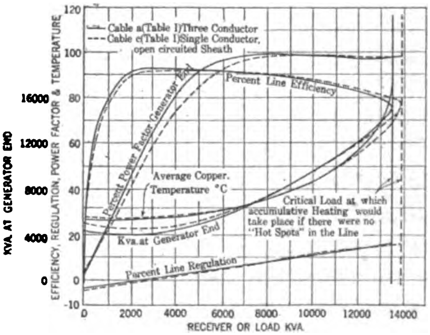

FIG. 17—COMPARISON OF LINE CHARACTERISTICS OF SINGLE- AND THREE-CONDUCTOR CABLES (SEE TABLE VII)—60-CYCLES—ALL VALUES PER CABLE—LENGTH OF LINE 50 MILES

The calculations for a fifty-mile line are tabulated in Table VII. They are based on the assumption of constant voltage at load or receiver end and a load power factor of 85 per cent. The more important characteristics are given in curve form in Fig. 17. There is little to choose between the two cables as far as general line characteristics are concerned. They have practically equal efficiencies, regulation, etc.

A cable line fifty-miles in length is exceptional. This length was chosen partly because it gives a severe comparison between the two cables and partly to show that there is nothing objectionable in such long lines other than the large charging capacity at no load. It amounts to approximately 5000 kv-a. or 100 kv-a. per mile of cable. High-potential testing would require at least 10,000 kv-a. unless made at a lower frequency. Few operating companies would have, or would care to invest, in the necessary a-c. equipment for this testing. A high-potential direct-current testing set would meet the conditions better than anything else.

In long cable lines such as considered the current and voltage, and hence the copper and dielectric losses, vary appreciably over the length of line. Fortunately at heavy loads where heating is a limiting factor the copper and dielectric losses vary in opposite directions, the increase in one heing more or less compensated for by decrease in the other. Consequently, if there were no inequalities in the heat dissipating ability of the duct lines the heating would be uniformly distributed and the copper temperature rise would be practically the same over the whole length of line.

The only inequalities we are concerned with are "hot spots," where maximum heating and temperature rise occur. These hot spots may be anywhere in the length of line and due to the complicated relationship between copper and dielectric losses there is always doubt as to just what position of hot spot would cause the severest heating.

In Fig. 18 we have accordingly assumed hot spots for the extreme conditions, that is, at the two ends of the line. The curves in this figure were calculated only for the single conductor cable (c) by the method explained in Appendix C and the data in Table VII. The empirical formula for the dielectric conductance of cable (c) (Formula 22, Appendix C) found by the $\Sigma \triangle$ method is

$$g_d = 0.079 \times 10^{-9} + 0.306 \times 10^{-13}(T')^{2.65}$$

This formula holds only up to 90 deg. cent. but Fig. 18 shows that accumulative heating is reached at a temperature below this. Fig. 18 also shows that the worst position of hot spot is at receiver or load end. The critical load at which accumulative heating starts here is 11,200 kv-a. If the hot spot is at generator end the critical load is 11,800 kv-a. This difference is due to a greater increase in current, and hence copper loss, at load end over the correspondingly higher voltage and dielectric loss at generator end. A study of Table VII and Figs. 17 and 18 brings out many other interesting features which we will not deal with. It can readily be seen that the worst position of hot spot is not always at receiver end but depends upon the length of line, load power factor and relative dielectric and copper losses.

Since in this particular case the limiting position is at receiver end, the hot spot characteristics of cables (*a*) and (*c*) are compared at this point in Fig. 19. The calculation of these curves is very simple and was first suggested in the paper by Bang and Louis.[11] It furnishes a splendid means of comparing the merits of different cables and would be especially valuable if a standard duct of known heat dissipating ability was adopted, as previously recommended. Fig. 19 does not indicate any appreciable difference between cables (a) and (c). Cable (c) is slightly favored since it has a critical load of 11,200 kv-a., while that of cable (a) is 11,050 kv-a. The introduction of this hot spot at the receiver end, based on the assumption of 25 per cent less heat dissipating ability than the average, has lowered the critical load capacity of cable (a) 18.5 per cent and of cable (c) 19.5 per cent. The safe load ratings are therefore, lowered about the same amount.

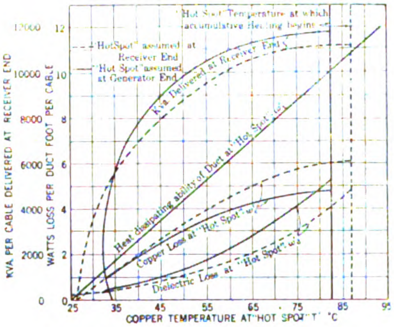

FIG. 18—"HOT SPOT" CHARACTERISTICS OF CABLE C (SEE TABLE VII AND FIG. 17)—60 CYCLES — SURROUNDING SOIL TEMPARATURE 25 DEG. CENT. —OPEN-CIRCUITED SHEATH

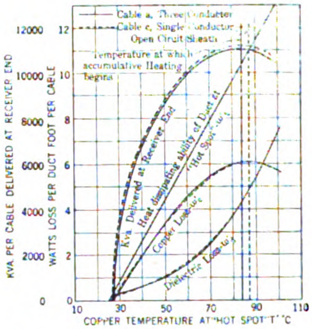

FIG. 19 — COMPARISON OF "HOT SPOT" CHARACTERISTICS OF SINGLE- AND THREE-CONDUCTOR CABLES (SEE TABLE VII) "HOT SPOT" ASSUMED AT RECEIVER END

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[11] "The Influence of Dielectric Losses on the Rating of High-Tension Cables," by Bang and Louis, A. I. E. E., Feb. 1917.

ADVANTAGES AND DISADVANTAGES OF SINGLE-CONDUCTOR CABLE

Both the line and hot spot characteristics of cables (a) and (c) are so closely similar that they can be neglected in a general comparison of the two types of cables. The comparison is thereby greatly simplified and allows a study of other important factors that might otherwise be over-shadowed.

In changing from (a) to (c) with open-circuited sheath there is a saving in copper of 70 per cent, a tremendous advantage. This is reduced to 66 per cent when the necessary neutral ground wire is added and a line of three cables only is considered. The saving will approach 70 per cent according to the number of cables in the line, as a single neutral wire can be made to serve any number of cables. Other advantages such as greater simplicity and reliability of joints and pot heads, and lesser possibility of insulation deterioration because of uniform radial stressing have already been dealt with.

There are two other advantages we would like to point out before taking up the disadvantages. One of these, and a very important one in large systems of almost unlimited short-circuit power is, that all short circuits from cable failures will be single phase. The chance of short circuits between phases is very remote. The majority of three-conductor cable failures ultimately form between phases and as every one knows they are a much more severe trial on the system.

The other advantage is in the possibility of substituting aluminum conductors. An equivalent aluminum conductor has a cross section ratio to copper of about 1.63 to 1. It would not be feasible to substitute aluminum in the three conductor cable (a) because the conductor diameter is already the largest practical size. In cable (c) the substitution of aluminum merely means a reduction in the conductor core without otherwise affecting the dimensions. Whether this substitution would be desirable or not would depend upon the existing market price of aluminum and copper, although the difficulty of splicing aluminum conductors would counterbalance to some extent any advantage in cost.

The disadvantages of single-conductor cable that need be seriously considered are: unbalancing of phase inductance and induced sheath voltage or current, according to whether the sheath is open- or short-circuited.

The standard duct used today has a rectangular cross section.

This means that three single conductor cables installed to transmit three phase power must be spaced at the corners of a right angle triangle with consequent unbalancing of the phase inductance. In short lines this unbalancing would be of little consequence but in long lines transposition would have to be resorted to, the problem being handled in exactly the same way as in over head transmission.

By using special ducts of round cross section the cables could be spaced equilaterally. If the conduit line consisted of only one three-cable circuit there would be no need of transposition. If, however, more than three cables, six for instance, were closely spaced in one conduit mutual inductance between circuits would cause unbalancing to about the same degree as that caused by unsymmetrical spacing of three cables only.

It is not within the scope of this paper to deal with phase unbalancing or advise when transposition is necessary or when it is not necessary. A theoretical consideration of the subject would involve complicated and tedious mathematics and would be of little practical use. It is a subject that had best be left to the practical experience and judgment of operating engineers. Transposition can be made at manholes without much extra cost and to be on the safe side perhaps it should generally be used, especially so when parallel operation of two or more circuits is attempted.

Under a previous heading it has been shown that single-conductor cable can be operated at 25 cycles with sheaths bonded together and grounded in two or more phases. The short circuited sheath current introduces an additional loss but this is a small item compared with the great saving in copper accomplished in changing over from three-conductor cable. This form of connection is shown diagrammatically in Fig. 20. (Connection No. 1.) The sheaths remain at ground potential over their whole length with an absence of bothersome leakage between sheaths and the special precautions needed to overcome it. Fig. 20 shows the sheaths bonded together and grounded at the ends in the same way three-conductor cable sheaths are, the only difference being the intermediate bonds, necessary to relieve the sheaths of the charging current that accumulates along their length. If the intermediate bonds are spaced every mile or two the loss due to charging current flowing along sheaths will be negligible. Greater care must be taken to assure reliable and permanent bonding and grounding than with three-conductor cable. If one of the sheaths was accidently freed of its bond connections electromagnetic and electrostatic induction would tend to raise it to a high potential. There would not only be danger of destroying the sheath or causing injury to workmen but there would also be danger of exploding accumulated gases by electrostatic sparking.

The 25-cycle effective resistance of cable (c) with short-circuited sheath and 6.74-in. spacing was calculated (see Formula 2, Appendix B) and found to be 6.3 per cent higher than effective resistance with open-circuited sheath at 25 deg. cent. and 5.3 per cent higher at 50 deg. cent. The decrease at higher temperature is due to increase in sheath resistance. There can be no question concerning the desirability of short-circuiting the sheath of cable (c) for 25-cycle operation. Also, the superiority in every way over cable (a) is very apparent.

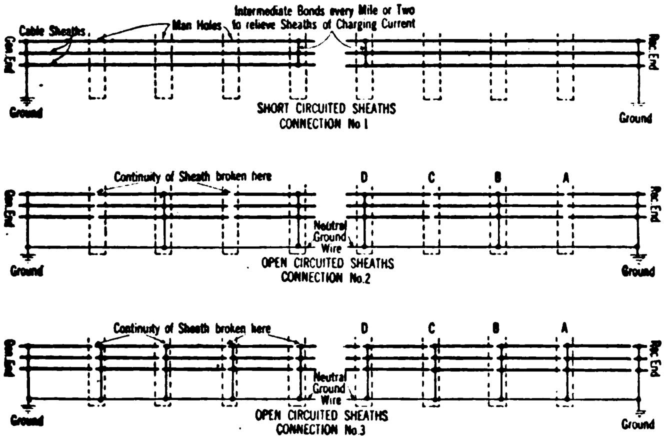
Intermediate Bonds every Mile or Two to relieve Sheaths of Charging Current
Cable Sheaths
Man Holes
Gen. End
Rec. End
Ground
Ground
SHORT CIRCUITED SHEATHS CONNECTION No 1
Continuity of Sheath broken here
D
C
B
A
Gen. End
Rec. End
Neutral Ground Wire
Ground
Ground
OPEN CIRCUITED SHEATHS CONNECTION No.2
Continuity of Sheath broken here
D
C
B
A
Gen. End
Rec. End
Neutral Ground Wire
Ground
Ground
OPEN CIRCUITED SHEATHS CONNECTION No.3

FIG. 20—SHOWING DIFFERENT METHODS OF BONDING AND GROUNDING SINGLE-CONDUCTOR CABLE SHEATHS

At 60 cycles, 25 deg. cent., the effective resistance is 30 per cent higher with short-circuited sheath and 26 per cent higher at 50 deg. cent. This means that approximately 28 per cent more copper in cable (c) would give practically the same line loss, efficiency, regulation, etc., with short-circuited sheath as that given in Table VII and Figs. 17, 18 and 19 for open-circuited sheath. Since the neutral ground wire would be eliminated it actually means only 15 per cent more copper for a three cable line. *There would still be a saving in copper* *of* 61 *per cent in changing over from cable* (*a*) *to cable* (*c*) *compared with* 66 *per cent saving when* (*c*) *is operated with open-circuited sheath.* This slight difference in copper saving is a significant and important feature and indicates very convincingly that, in this particular case, short-circuited sheath operation is much more favored even at 60 cycles.

A 28 per cent increase in copper changes the conductor cross section in cable (c) from 275,000 to 350,000 cir. mils. The data in Table VII and Figs. 17, 18 and 19 were calculated for a conductor of 275,000 cir. mils and open-circuited sheath rather than for a conductor of 350,000 cir. mils and short-circuited sheath, not with any intention of emphasizing open-circuited sheath operation but because the data holds, practically, for either case and the assumptions furnish a convenient method of comparing open- and short-circuited sheath operation.

If cable (c) is limited to a temperature of 55 deg. cent. at hot spot, reference to Fig. 19 shows that it will be limited to an output of 9500 kv-a., or a current of 300 amperes. The induced sheath voltage per foot to neutral at receiver end with open-circuited sheath will be

$$e_s = 2\pi f M I_r$$

where M is the mutual inductance as represented in formula 6, Appendix B. Solving the above equation at 60 cycles; $e_s = 0.0000302 \times 300. = 0.00906$ volts per ft. length of cable.

In a fifty-mile line the total induced sheath voltage to neutral would be

$$0.00906 \times 264{,}000 = 2390 \text{ volts.}$$

The problem remains to break the sheath up into the shortest practical sections and arrange the ground connections in such a way that maximum sheath voltage will be reduced to a minimum. Connections Nos. 2 and 3 in Fig. 20 show the two best methods of doing this. In No. 2 the sheath is broken at every other manhole with ground bonds at intermediate manholes. The sheaths are broken and bonded at every manhole in Connection No. 3. Assuming the manholes 500 ft. apart, a maximum distance for this size cable, the sheath voltage along the length of line is given in Fig. 21 for the two different connections.

For connection No. 2 the maximum voltage from sheath to ground is 4.53 volts, therefore the voltage between sheaths of any two cables is $\sqrt{3} \times 4.53 = 7.85$ volts, and the voltage

	Cable a	Cable c
Number of cables per line	3	3
Spacing between conductor centers (inches)	1.38	$\sqrt[3]{6\times 6\times 8.5} = 6.74$
Length of line (miles)	50	50
Weight of conductor copper per line (pounds)	2,202,000	672,000
Weight of copper in No. O, B and S neutral ground wire (pounds)	0	84,000
Total weight of copper per line (pounds)	2,202,000	756,000
Total weight of lead per line (pounds)	6,021,000	6,240,000

TABLE VII

COMPARISON OF LINE CHARACTERISTICS—OF SINGLE AND THREE CONDUCTOR CABLES.

The Cables Compared Are Cables (a) and (c) in TABLE I.

60 Cycles—All Values per Cable per Duct to Neutral—Surrounding Soil 25 deg. cent. —See Appendix C for Nomenclature.

	Line constants				Volts to neutral		Current		Kv-a.		Power factor		Power		Line Efficiency per cent	Line Regulation per cent
T deg. cent	r_c 10^{-4}	L 10^{-6}	g_d 10^{-9}	C 10^{-9}	e_r 10^3	e_g 10^3	I_r	I_g	Rec.	Gen.	cos θr lagging	cos θ_g leading	W_r 10^3	W_g 10^3		
3 x 300,000 cm. Three Conductor Cable (Cable a, Table I.)																
27.44	0.1235	0.03765	0.880	0.1596	17.32	16.85	0	272.2	0	4,570	0.850	0.0305	0	150.5	0	– 2.79
27.44	0.1235		0.880	0.1596		17.40	122.4	237.0	2,120	4,120		0.4741	1,802	1,952	92.4	0.46
27.5	0.1235		0.880	0.1596		17.47	130.0	236.8	2,250	4,140		0.5013	1,912	2,066	92.6	0.86
28.0	0.1239		0.910	0.1597		17.71	188.7	241.5	3,260	4,260		0.6960	2,778	2,962	93.6	2.20
35.0	0.1268		1.515	0.1607		18.91	434.1	371.8	7,510	7,020		0.9984	6,390	7,005	91.1	8.40
45.0	0.1315		2.60	0.1625		19.71	589.1	505.2	10,250	9,970		*0.9960	8,710	9,945	87.6	12.11
55.0	0.1360		4.30	0.1646		20.25	681.6	594.0	11,790	12,000		*0.9881	10,010	11,858	84.5	14.45
75.0	0.1454		10.07	0.1695		20.95	769.7	701.0	13,310	14,710		*0.9810	11,310	14,380	78.8	17.32
90.0	0.1521		17.80	0.1739		21.10	780.6	746.0	13,520	15,750		*0.9844	11,480	15,478	74.3	17.93
100.0	0.1570		24.96	0.1769		21.25	777.5	770.0	13,460	16,310		*0.9856	11,430	16,043	71.3	18.48
275,000 cm. Single Conductor Cable (Cable c, Table I) Open Circuited Sheath.																
28.03	0.4016	0.145	0.320	0.05373	31.78	30.60	0	167.9	0	5,140	0.850	0.0365	0	187.8	0	– 3.86
28.0	0.4016		0.320	0.05373		30.64	3.65	166.2	115.9	5,100		0.0555	98.5	283.0	34.8	– 3.72
28.0	0.4016		0.320	0.05373		31.90	78.6	146.2	2,500	4,660		0.5060	2,126	2,311	92.0	0.376
28.03	0.4016		0.320	0.05373		31.99	82.5	145.9	2,620	4,660		0.5160	2,225	2,413	92.4	0.655
30.0	0.4043		0.380	0.05382		33.12	149.4	159.0	4,750	5,260		0.8240	4,038	4,346	92.9	4.05
35.0	0.4125		0.470	0.05410		34.59	235.2	205.9	7,470	7,120		0.9800	6,351	6,968	91.2	8.13
45.0	0.4272		0.830	0.05472		36.21	323.1	274.5	10,250	9,950		*0.9997	8,710	9,940	87.7	12.23
55.0	0.4425		1.350	0.05550		37.27	372.9	321.0	11,850	12,000		*0.9890	10,080	11,824	85.0	14.62
75.0	0.4730		3.040	0.05750		38.52	434.7	388.6	13,800	14,980		*0.9880	11,730	14,829	79.0	17.50
90.0	0.4960		5.300	0.05940		38.84	413.8	407.5	13,700	15,830		*0.9880	11,650	15,652	74.4	18.18

*Note: Generator power factor lagging.

across the break in continuity of any one sheath is 2 × 4.53 = 9.06 volts. The only advantage of connection No. 3 is that the voltage across break in sheath is reduced by half. If unsymmetrical spacing of cables is used, or there are two or more circuits closely spaced in one conduit, unbalancing of inductance will increase the maximum sheath voltage. The increase will not be more than about 20 per cent.

These potentials are so low that it would not be a difficult matter to insulate the sheaths and reduce leakage to a negligible quantity even in wet or flooded conduit. However, when the 15 per cent increase in copper for short circuited sheath operation of cable (c) is compared with the complications and expense of open-circuited sheath, such as, addition of neutral ground wire, the many breaks in continuity of sheath and the many bond connections that must be made absolutely secure, the balance in favor of short-circuited sheath stands out clearly.

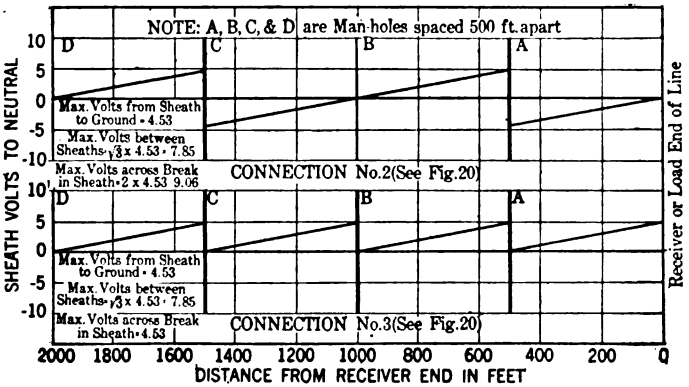

Fig. 21—Induced Sheath Voltage along Length of Single-Conductor Cable—Cable (c)—60 Cycles—300 amperes—Spacing 6.74 in.

With lower voltage, heavier current cable, cables No. 2 and 3 for instance, short-circuited sheath would mean an increase in copper of from 50 to 100 per cent, or more, for a 60-cycle line. The balance then turns in favor of open-circuited sheath, although the sheath potential is, unfortunately, somewhat higher than that given for cable (c) in Fig. 21. Potentials as high as 30 volts between sheaths might then have to be considered. The problem of insulating the sheaths would be increasingly difficult, but in some cases it would be the only alternative.

CONCLUSION.

The main features of single conductor cable operation, as we see them, have now been presented. Some of the work is new, although the greater part is merely a compilation and elaboration of previous work by many different engineers. Where possible credit has been given. It is obviously impossible to give full credit in every particular.

The valuable advice and assistance of the following engineers directly associated with us in this work is deeply appreciated; Messrs. J. J. Matson, D. A. Ballard, W. C. Hayman, J. L. R. Hayden and H. H. Dewey.

APPENDIX A

Nomenclature and Formulas for Dielectric Characteristics

The following nomenclature and formulas are used throughout the paper for single-conductor cable.[12]

e = impressed voltage = $E/\sqrt{3}$ when three phase is considered.
i_d = amperes (dielectric) per ft. length of cable.
w_d = watts loss (dielectric) per ft. length of cable.
$\cos\theta_d$ = dielectric power factor.
c = capacity in farads per ft. length.
K_{av} = relative permittivity (average through thickness.)
K_a = capacity per cm.^{3} of air = 0.08842×10^{-12} farads.
r_d = effective a-c. insulation resistance per ft. length.
ρ_{av} = effective a-c. insulation resistance per cm.^{3}
g = $\dfrac{d\,e}{d\,x}$ = voltage gradient.
g_{max} = voltage gradient at conductor surface.
l = length in cm. (1 ft. = 30.48 cm.)
b = radius in cm. to inner side of sheath.
a = radius in cm. of conductor.
f = frequency.

---

[12] For derivation of these formulas see, "Insulation Characteristics of High Voltage Cables," TRANS. A. I. E. E., June, 1917.

The dielectric circuit is considered as a parallel circuit, that is, the resistance and capacity are considered as being in parallel Then:

$$\cos \theta_d = \frac{w_d}{e\, i_d} \tag{1}$$

$$c = \frac{i_d \sin \theta_d}{2\, \pi\, f\, e} \tag{2}$$

For a single conductor cable in which the thickness of insulation consists of one kind only:

$$K_{av} = \frac{i_d \sin \theta_d \,.\, \log_\epsilon b/a}{(2\, \pi)^2\, l\, f\, e\, K_a} \tag{3}$$

$$\rho_{av} = \frac{2\pi\, l\, e^2}{w_d\, \log_\epsilon b/a} \tag{4}$$

$$g = \frac{e}{x \log_\epsilon b/a} \quad \text{or} \quad g_{max} = \frac{e}{a \log_\epsilon b/a} \tag{5}$$

THREE-CONDUCTOR CABLE

The calculations of dielectric characteristics for a three-conductor cable are greatly simplified if worked to neutral instead of between conductors.

e = impressed voltage to neutral = $E/\sqrt{3}$

i_d = amperes (dielectric) per con. per ft. length.

w_d = three phase watts loss (dielectric) per cond. per ft. length.

$3\, w_d$ = total three phase loss (dielectric) per ft. length of cable.

$\cos \theta_d$ = dielectric power factor (average for cable cross section.)

c_1 = capacity in farads per ft. between one cond. and sheath.

c_4 = capacity in farads per ft. between any two conds.

c_n = capacity in farads per ft. of one cond. to neutral.

K_{av} = relative permittivity (average through cross section.)

l = length in cm. (1 ft. = 30.48 cm.)

a = radius in cm. of conductor.

b = radius in cm. to inner side of sheath.
d = distance in cm. between axis of a and b.

Approximate formulas (**6**) and (**7**) for calculating the capacity of three conductor cable, as derived by Alex. Russell, are given below:

$$c_1 = K_{av}\left(\frac{0.1693 \times 10^{-10}}{\log_\epsilon \frac{b^6 - d^6}{3\,(b^3\,d^2\,a)}}\right) \qquad \textbf{(6)}$$

$$c_4 = K_{av}\left[\frac{0.3384 \times 10^{-10}}{6 \log_\epsilon \left\{\frac{d\sqrt{3}}{a} \cdot \frac{b^2 - d^2}{b^4 + b^2\,d^2 + d^4)^{1/2}}\right\}} - \frac{0.3384 \times 10^{-10}}{6 \log_\epsilon \frac{b^6 - d^6}{3\,(b^3\,d^2\,a)}}\right] \qquad \textbf{(7)}$$

It is apparent that the capacity between conductor and sheath c_1 is to ground or neutral. The capacity between conductors c_4 is converted to neutral by multiplying by three.

$$\therefore c_n = c_1 + 3\,c_4 \qquad \textbf{(8)}$$

$$\text{also, } c_n = \frac{i_d \sin\theta_d}{2\,\pi\,f\,e} \qquad \textbf{(9)}$$

$$3\,w_d = 3\,(e\,i_d \cos\theta_d) \qquad \textbf{(10)}$$

APPENDIX B

Theoretical Solution of Parallel Single Conductor Cables with Non-Magnetic Sheaths

Since cable conductors are stranded the effect of this stranding on the calculated inductance although fairly small, must be corrected for. Referring to Fig. 22 an accurate way of doing this is to assume a solid conductor of the same cross section as the stranded and having an average radius equal to that of the stranded.

Let a_0 and b_0 be the actual inner and outer radii of the stranded conductor, a_1 and b_1 the radii of the equivalent solid conductor and A the cross section.

$$A = \pi\,(b_1^2 - a_1^2) \quad \text{and } b_0 + a_0 = b_1 + a_1$$

$$\left.\begin{aligned} \text{Therefore: } b_1 &= \frac{b_0 + a_0}{2} + \frac{A}{2\,\pi\,(b_0 + a_0)} \\ a_1 &= \frac{b_0 + a_0}{2} - \frac{A}{2\,\pi\,(b_0 + a_0)} \end{aligned}\right\} \qquad (1)$$

In Fig. 22 let us assume that the two sheaths are short circuited together and the distance between the two end bonds is length l. (No current flows across the intermediate bonds if the resistance of the end bonds is negligible. If resistance is inserted in end bonds current will flow across intermediate bonds.)

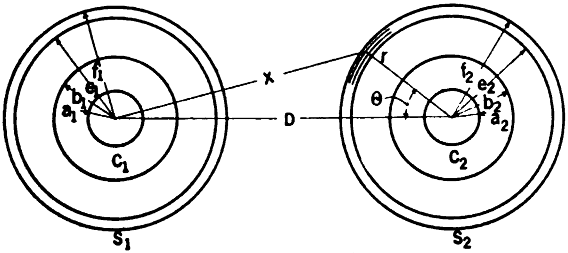

FIG. 22

It can be seen that flux set up by current in the sheath interlinks all of the current in the concentric conductor. Hence the sheath has no self-inductance. The bonds, however, have self-inductance but since they are short compared with length l the inductance is very small in comparison with the sheath resistance between bonds and can be neglected.

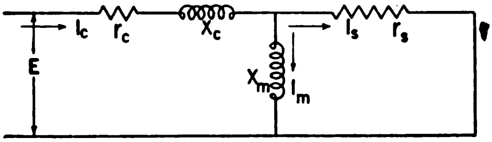

FIG. 23

In deriving the following formulae one cable only will be considered and all values worked to neutral. That is, only one-half of the circuit in Fig. 22 will be considered. The results can then be applied to either single phase circuits or polyphase circuits having symmetrical arrangement of cables. A unit length of 1000 ft. of cable will also be considered.

Let:

r_c = ohms effective a-c. resistance of copper.
L_c = henries self inductance of conductor to neutral.
M = henries mutual inductance of conductor and sheath to neutral.
r_s = effective a-c. resistance of sheath and bonds to neutral.
i.e. r_s = total resistance of closed circuit path to neutral.

The arrangement in Fig. 22 is equivalent to an ordinary transformer with short circuited secondary and with zero reactance in the secondary. The equivalent transformer circuit is shown in Fig. 23.

$$Z_c = r_c - j\,2\,\pi\,f\,L_c$$

$$Y_m = \frac{j}{2\,\pi\,f\,M} \text{ and } Y_s = \frac{1}{r_s}$$

$$Y' = Y_m + Y_s = \frac{X_m + j\,r_s}{X_m\,r_s}$$

$$Z' = \frac{X_m^2\,r_s}{X_m^2 + r_s^2} - j\,\frac{X_m\,r_s^2}{X_m^2 + r_s^2}$$

$$Z_{eff} = Z_c + Z' = \left(r_c + \frac{X_m^2\,r_s}{X_m^2\,r + r_s^2}\right) - j\left(X_c + \frac{X_m\,r_s^2}{X_m^2 + r_s^2}\right) \qquad (2)$$

Where

$$r_{eff} = r_c + \frac{X_m^2\,r_s}{X_m^2 + r_s^2} \text{ and}$$

$$X_{eff} = 2\,\pi\,f\,L_{eff} = X_c + \frac{X_m\,r_s^2}{X_m^2 + r_s^2}$$

for open circuited sheath $r_s = \infty$

therefore $Z_{eff} = r_c - j\,(X_c + X_m)$ (3)

The vector diagram of the short circuit currents and voltages is given in Fig. 24.

If the constants r_c, r_s, M and L_c are known all of the characteristics can be easily calculated.

Effective resistance r_c is the a-c. value that would be measured with open circuited sheath. It can in most cases be assumed as equal to the measured d-c. value. Eddy currents in stranded cable conductors have been shown both theoretically and by actual measurement to be negligible. In some cases, especially when coreless conductors are used, skin effect must be corrected for. Heaviside's formula for this correction as revised by Russell is given below (see *Philosophical Magazine* April, 1909, p. 545).

$$\frac{r_c}{r_c'} = 1 + \left(\frac{4\pi\mu\omega}{\rho}\right)^2 \left\{ \frac{(7a^2 - b^2)(a^2 - b^2)}{192} + \frac{b^2 a^4}{8(b^2 - a^2)} \log_\epsilon \frac{b}{a} - \frac{b^2 a^6}{4(b^2 - a^2)^2} \left(\log_\epsilon \frac{b}{a}\right)^2 \right\} \quad (4)$$

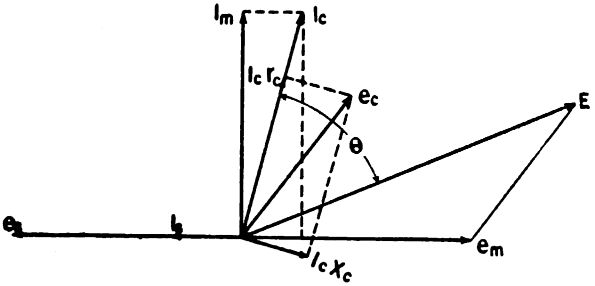

Fig. 24

where:

r_c = effective a-c. resistance.
r_c' = measured d-c. resistance
a = inside radius in cm. (for coreless cond. a = 0)
b = outside radius
μ = permeability = 1
ρ = specific resistance in C. G. S. units
ω = $2\pi f$

With open circuit sheath there is a small circulating current in the sheath due to unsymmetrical flux distribution. This also adds to r_c but Berg has shown theoretically (see Berg's *Electric Energy*, p. 57) and actual measurements prove that it is inappreciable. We can, then, ignore the sheath entirely when open-circuited.

Effective resistance r_s is equal to the measured d-c. value. The high resistivity of sheath metal and the fact that the sheath is a comparatively thin shell eliminates skin effect.

Mutual Inductance M can be defined as the sum of the total and partial interlinkages of the flux from the conductor current (unit current) with the filaments of unit sheath current.

The formulae for total and partial interlinkages as used in developing M and L_c were derived by Alex Russell (see Russell's "*Alternating Currents*" Vol. I pp. 55 to 59.

Referring to Fig. 22:

$$-M_0 = M^{\text{I}} + M^{\text{II}} + (M^{\text{III}} + M_{s_2}) \tag{5}$$

where M_0 is in C. G. S. units, so that henries per 1000 ft.,

$$M = 0.305 \times 10^{-4} M_0$$

$$M^{\text{I}} = -\frac{1}{I_c I_s} \int_{e_1}^{f_1} \phi c_1 \, i_{s_1} \text{ partial interlinkages.}$$

and:

$$\phi c_1 = \frac{2 I_c}{x} dx, \; - i_{s_1} = -\frac{x^2 - e_1^2}{f_1^2 - e_1^2} I_s$$

integrating:

$$M^{\text{I}} = -1 + \frac{2 e_1^2}{f_1^2 - e_1^2} \log_\epsilon \frac{f_1}{e_1}$$

$$M^{\text{II}} = -\frac{1}{I_c I_s} \int_{D\; f_1}^{D - f_2} \phi_{c_1} i_{s_1} \text{ total interlinkages}$$

where:

$$\phi_{c_1} = \frac{2 I_c}{x} dx \text{ and } - i_{s_1} = - I_s$$

integrating:

$$M^{\text{II}} = -2 \log_\epsilon \frac{D - f_2}{f_1}$$

$$M^{\text{III}} = -\frac{1}{I_c I_s} \int_{D - f_2}^{D + f_2} \phi_{c_1} i_{s_1} \text{ total interlinkages}$$

where;

$$\phi_{c_1} = \frac{2\,I_c}{x}\,dx \text{ and } -i_{s_1} = -I_s$$

integrating:

$$M^{\prime 11} = -2\log_e \frac{D+f_2}{D-f_2}$$

$$M_{s_2} = \frac{1}{I_c I_s}\int_{D-f_2}^{D+f_2} \phi_{c_1}\, i_{s_2} \text{ partial interlinkages}$$

In the sheath cross section S_2 consider a concentric ring of radius r and thickness dr. Then

$$x^2 = r^2 + D^2 - 2\,D\,r\cos\theta, \text{ keeping } r \text{ constant}$$

$$x\,dx = D\,r\sin\theta\,.\,d\,\theta$$

The current i_{s_2}' in this cylinder is equal to

$$\frac{2\,\pi\,r\,dr\,I_s}{\pi\,(f_2^2 - e_2^2)}\,.$$

Hence the part of $\Sigma\,\phi_{c_1} i_{s_2}$ due to the current in cylinder is

$$\int_{D-r}^{D+r} \frac{\theta}{\pi}\, i_{s_2}'\,.\,\frac{2\,I_c}{x}\,dx$$

for $\dfrac{\theta}{\pi}\, i_{s_2}'$ is the number of tubes of current in this elementary cylinder intercepted by a circle of radius x and

$$\frac{2\,I_c}{x}\,dx = \phi_{c_1}$$

Since $x\,dx = r\,D\sin\theta\,.\,d\,\theta$
this may be written

$$\frac{I_c i_{s_2}'}{\pi}\int_0^{\pi} \frac{2\,r\,D\sin\theta\,.\,d\,\theta}{r^2 + D^2 - 2\,r\,D\cos\theta}$$

$= 2\;I_c i_{s_2}' \log\,(r + D) - 2\;I_c i_{s_2}' \log D$, for the

part $-\dfrac{I_c i_{s_2}'}{\pi}\displaystyle\int_0^{\pi} \log\left(1 - \frac{2\,r}{D}\cos\theta + \frac{r^2}{D^2}\right)d\,\theta = 0$

Therefore up to $D + r$ this elementary cylinder contributes;

$$2\, I_c\, i s_2' \,[\log\,(r + D) - \log D\,] \qquad \textbf{(a)}$$

to $\Sigma\, \phi_{c1}\, i s_2$. It also contributes from $D + r$ to $D + f_2$

$$\int_{D+r}^{D+f_2} i s_2' \,\frac{2\, I_c}{z}\, d\,z = 2\, I_c\, i s_2' \,[\log\,(D + f_2) - \log\,(D + r)] \quad \textbf{(b)}$$

The total contribution by this elementary cylinder is $(a) + (b)$

$$= 2\, I_c\, i s_2' \log\,(D + f_2) - 2\, I_c\, i s_2' \log D$$

Substituting $\dfrac{2\, r\, dr\, I_s}{f_2^2 - e_2^2}$ for $i s_2'$ and integrating for $r = e_2$ to $r = f_2$ we get

$$M s_2 = 2 \log \frac{D + f_2}{D}$$

Adding all the components in (**5**) and simplifying, we get:

$$M_0 = \left(2 \log_\epsilon \frac{D}{f_1}\right) - \left(\frac{2\, e_1^2}{f_1^2 - e_1^2} \,.\log_\epsilon \frac{f_1}{e_1}\right) + 1 \text{ or,}$$

$$M = \left[\left(2 \log_\epsilon \frac{D}{f_1}\right) - \left(\frac{2\, e_1^2}{f_1^2 - e_1^2} \,.\log_\epsilon \frac{f_1}{e_1}\right) + 1\right]$$

0.305×10^{-4} henries per 1000 ft. of conductor (to neutral) (**6**)

Self Inductance L_c. The most convenient way of obtaining the short circuit self inductance L_c of the conductors is to subtract M from the open circuit effective inductance L. When the sheath is open circuited it has no effect of any kind as already described. L is then actually the open circuit self inductance of the conductors and reference to Figs. 22 and 23 show $L = L_c + M$ where L is in henries per 1000 ft. and $= 0.305 \times 10^{-4}\, L_0$

$$L_0 = L c_1{}^{\mathrm{I}} + L c_1{}^{\mathrm{II}} + (L c_1{}^{\mathrm{III}} + M c_2) \qquad \textbf{(7)}$$

The integral equations for the above components of L_0 work out in exactly the same way as those for the corresponding components of M_0, always giving the interlinkages $\phi\, i$ their proper sign. Thus:

$$Lc_1{}^{I} = \frac{1}{I_c^2}\int_{a_1}^{b_1} \phi c_1\, ic_1 \text{ partial interlinkages, where:}$$

$$\phi c_1 = \frac{2\, I_c}{b_1^2 - a_1^2}\left(x - \frac{a_1^2}{x}\right)dx \text{ and } ic_1 = \frac{x^2 - a_1^2}{b_1^2 - a_1^2} I_c$$

hence:

$$Lc_1{}^{I} = \frac{2\, a_1^4}{(b_1^2 - a_1^2)^2}\log_\epsilon \frac{b_1}{a_1} + \frac{1}{2}\,\frac{b_1^2 - 3\, a_1^2}{b_1^2 - a_1^2}$$

$$Lc_1{}^{II} = \frac{1}{I_c^2}\int_{b_1}^{D - b_2} \phi c_1\, ic_1 = 2\,\log_\epsilon \frac{D - b_2}{b_1}$$

$$Lc_1{}^{III} = \frac{1}{I_c^2}\int_{D - b_2}^{D + b_2} \phi c_1\, ic_1 = 2\log_\epsilon \frac{D + b_2}{D - b_2}$$

$$Mc_2 = -\frac{1}{I_c^2}\int_{D - b_2}^{D + b_2} \phi c_1\, ic_2 \text{ partial interlinkages where the}$$

method of integrating is the same as that for Ms_2.
Therefore:

$$Mc_2 = -2\log_\epsilon \frac{D + b_2}{D}$$

Adding all components in (7) and simplifying we get:

$$L_0 = \left(2\log_\epsilon \frac{D}{b_1}\right) + \left(\frac{2\, a_1^4}{(b_1^2 - a_1^2)^2} \,.\, \log_\epsilon \frac{b_1}{a_1}\right) + \left(\frac{1}{2}\,\frac{b_1^2 - 3\, a_1^2}{b_1^2 - a_1^2}\right), \text{ or}$$

$$L = \left[\left(2\log_\epsilon \frac{D}{b_1}\right) + \left(\frac{2\, a_1^4}{(b_1^2 - a_1^2)^2} \,.\, \log_\epsilon \frac{b_1}{a_1}\right) + \left(\frac{1}{2}\,\frac{b_1^2 - 3\, a_1^2}{b_1^2 - a_1^2}\right)\right] 0.305 \times 10^{-4}$$

henries per 1000 ft. of conductor (To neutral) (8)

Since there is no self inductance of the conductor beyond the sheath the value L_c can be independently obtained.

$$L_{c0} = Lc_1^{\text{I}} + Lc_1^{\text{IV}} + (Lc_1^{\text{V}} + M^{\text{I}}),$$

where Lc_1^{I} and M^{I} are the same components as defined above.

$$L^{\text{IV}}_{c1} = \frac{1}{I_c^2} \int_{b_1}^{e_1} \phi c_1 \, i c_1 = 2 \log_\epsilon \frac{e_1}{b_1}$$

$$L^{\text{V}}_{c1} = \frac{1}{I_c^2} \int_{e_1}^{f_1} \phi c_1 \, i c_1 = 2 \log_\epsilon \frac{f_1}{e_1}$$

The values of L_c worked out by these two different methods check exactly.

APPENDIX C

Line Characteristics of Underground Cables

The work is greatly simplified if only one cable is considered in the calculations of line characteristics, whether single or three conductor cables are used in the conduit line. Values can then be worked out per cable per duct. Further simplicity is obtained by considering all values such as voltage, inductance, capacity, etc. to neutral instead of between lines.

Single-Conductor Cable. When single-conductor cable is used the inductance depends upon the spacing between cables. Usually the duct arrangement requires that they be spaced at the corners of a right angle triangle. The phase inductance is then unbalanced. When this unbalancing is appreciable it can be conveniently compensated for by transposition at man holes. The equivalent spacing to be used in calculating inductance is;

$$D = \sqrt[3]{a\,b\,c} \tag{1}$$

where a, b and c are the respective sides of the triangle. With proper transposition the proximity of other single conductor cable lines can be ignored.

Three-Conductor Cable. The spacing between conductors is fixed and the conductors are symmetrically arranged, D is therefore the actual distance between conductor centers. Since all values are to be calculated per cable the assumed conductor cross section, line current, dielectric loss and capacity to neutral will be three times the actual values per conductor, and the assumed resistance and inductance to neutral will be one-third the actual values per conductor.

Formulas (**2**) and (**3**) below were developed by Dr. Steinmetz* for a line having distribution impedance and admittance.

$$\underset{\cdot}{E}_1 = \underset{\cdot}{E}_2\left(1+\frac{Z\,Y}{2}\right) \pm Z\,\underset{\cdot}{I}_2\left(1+\frac{Z\,Y}{6}\right) \qquad (\mathbf{2})$$

$$\underset{\cdot}{I}_1 = \underset{\cdot}{I}_2\left(1+\frac{Z\,Y}{2}\right) \pm Y\,\underset{\cdot}{E}_2\left(1+\frac{Z\,Y}{6}\right) \qquad (\mathbf{3})$$

The plus sign supplies when $\underset{\cdot}{E}_1$ and $\underset{\cdot}{I}_1$ are at or towards generator end and $\underset{\cdot}{E}_2$, $\underset{\cdot}{I}_2$ at or towards receiver load end. The negative sign applies when the directions are reversed.

In practically all cases the voltage is held constant at receiver end and value of load current and power factor assumed, letting the generator voltage, current and power factor come what they will. The above formulas then take the form:

$$\underset{\cdot}{e}_g = \underset{\cdot}{e}_r\left(1+\frac{Z\,Y}{2}\right) + Z\underset{\cdot}{I}_r\left(1+\frac{Z\,Y}{6}\right) \qquad (\mathbf{4})$$

$$\underset{\cdot}{I}_g = \underset{\cdot}{I}_r\left(1+\frac{Z\,Y}{2}\right) + Y\,\underset{\cdot}{e}_r\left(1+\frac{Z\,Y}{6}\right) \qquad (\mathbf{5})$$

Where:

$\underset{\cdot}{e}_r = e_r' + o\,j =$ receiver end voltage to neutral (constant).

$\underset{\cdot}{I}_r = i_r' + i_r''\,j =$ assumed receiver line current (lagging p. f).

$\underset{\cdot}{e}_g = e_g' \pm e_g''\,j =$ generator end voltage to neutral.

$\underset{\cdot}{I}_g = i_g' \pm i_g''\,j =$ line current at generator end.

$Z = l\,(r_c - j\,x)$ and $x = 2\,\pi\,f\,L$

$Y = l\,(g_d - j\,b_d)$ and $b_d = 2\,\pi\,f\,c$.

where;

l = length of line considered in ft.

r_c = resistance per ft. of conductor in ohms.

L = inductance to neutral per ft. of cond. in henries.

g_d = conductance to neutral of insulation per ft. in mhos.

c = capacity to neutral per ft. in farads.

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*"Engineering Mathematics" p. 204, McGraw-Hill Co.

Inductance L is the only line constant that is independent of duct temperature. The formulas for L (or L_{eff} when single conductor cable with short circuited sheath is used) are given in Appendix B, Formulas 8 and 2.

Resistance r_c varies with duct temperature. It is the effective a-c. resistance discussed in Appendix B, and therefore includes skin effect when this is appreciable. To be on the safe side the copper conductivity should be taken as 98 per cent in calculating skin effect by formula (**4**), Appendix B. Actually, the copper conductivity is usually between 99 and 100 per cent. In the majority of cases skin effect is negligible and the d-c. resistance sufficiently representative (with single-conductor cable and short circuited sheath the resistance is represented by r_{eff}.) The standard formula for d-c. copper resistance is:

$$r = r_{25} [1 + 0.00378 (T - 25)] \qquad (\mathbf{6})$$

where;

r_{25} = resistance at 25 deg. cent. (98 per cent copper).
T = copper temperature in deg. cent.

Conductance g_d of the cable insulation is an important line constant because of its rapid increase with temperature.

$$g_d = 1/r_d = w_d/e^2 \quad \text{(see Appendix A).}$$

It is much better to measure g_d for the particular cable used. However, if sufficient data are available from other cables of the same type g_d can be approximated, as described in the body of the paper and Appendix A. A small error is brought in by assuming the temperature, and consequently g_d, uniform through cable cross section. Usually, in duct operation, the sheath temperature is about 10 per cent lower than the conductor temperature. If necessary this error can be corrected for. In the majority of cases it can be ignored.

Capacity c should also be measured when possible, although it can be estimated closely by the method referred to above in connection with g_d. The variation of c with temperature is small in good grade impregnated paper, about 15 per cent from 25 deg. cent. to 100 deg. cent. It is large enough to be considered if accurate results are desired.

HEATING CHARACTERISTICS OF DUCT SYSTEM

Referring to Fig. 17, let;

w_d = *average* dielectric loss per duct. ft.
w_c = *average* copper loss per duct ft.
$w_t = w_d + w_c$ = av. total loss per duct ft.
T_1 = temperature of surrounding soil
T = *average* copper temperature as measured by by resist drop.

Since w_t is a straight line function of T the formula is:

$$l\,w_t = A\,l\,(T - T_1) \qquad (7)$$

where A is a constant and l is length of line in feet.

RELATION BETWEEN LOAD AND AVERAGE TEMPERATURE

For any assumed value of temperature T there is a certain value of continuous load that will satisfy the conditions. The problem remains to determine this load.

Impedance Z and admittance Y are calculated at the chosen temperature T and inserted in Formulas **4** and **5**. The receiver voltage e_r and power factor $\cos\theta_r$ are known and assumed to be constant at all loads. Then, in Formulas **4** and **5** the only unknown values are $\underset{\cdot}{e}_g$, $\underset{\cdot}{I}_g$ and the numerical value I_r, since;

$$\underset{\cdot}{I}_r = I_r \cos\theta_r + j\,I_r \sin\theta_r \qquad (8)$$

We can, therefore, solve for $\underset{\cdot}{e}_g$ and $\underset{\cdot}{I}_g$ in terms of I_r.

Simplifying (**4**) and (**5**) they take the form:

$$\underset{\cdot}{e}_g = (a_1 + a_2 I_r) + j\,(b_1 + b_2 I_r) \qquad (9)$$

$$\underset{\cdot}{I}_g = (a_3 + a_4 I_r) + j\,(b_3 + b_4 I_r) \qquad (10)$$

where;

$$e_g' = a_1 + a_2 I_r, \text{ and } e_g'' = b_1 + b_2 I_r$$
$$i_g' = a_3 + a_4 I_r, \text{ and } i_g'' = b_3 + b_4 I_r$$

The power at generator end is:

$$W_g = e_g'\,i_g' + e_g''\,i_g'' \qquad (11)$$

or, taking care to give the numerical values of the constants a_1, b_1, etc. their correct sign;

$$W_g = (a_1 + a_2 I_r)\,(a_3 + a_4 I_r) + (b_1 + b_2 I_r)\,(b_3 + b_4 I_r) \qquad (12)$$

The power at receiver end is:

$$W_r = e_r\,i_r'$$

or

$$W_r = e_r I_r \cos \theta_r \tag{13}$$

The total line loss is:

$$l w_t = W_g - W_r \tag{14}$$

or, combining (**7**), (**12**) and (**13**) we have:

$$A l (T - T_1) = (a_1 + a_2 I_r)(a_3 + a_4 I_r) + (b_1 + b_2 I_r)(b_3 + b_4 I_r) - e_r I_r \cos \theta_r \tag{15}$$

in which I_r, being the only unknown can be solved for.

$$\frac{W_r}{W_g} \times 100 = \text{per cent line efficiency} \tag{16}$$

$$\frac{e_g - e_r}{e_g} \times 100 = \text{per cent line regulation} \tag{17}$$

RELATION BETWEEN LOAD AND HOT SPOT TEMPERATURE

Referring again to Fig. 17 let;

w_d' = dielectric loss per duct ft. at hot spot.
w_c' = copper loss per duct ft. at hot spot.
$w_d' + w_c' = w_t'$ = total loss per duct ft. at hot spot.
T_1 = temp. of surrounding soil
T' = copper temp. at hot spot.

Since w_t' is a straight line function of T' the formula is;

$$w_t' = A' (T' - T_1) \tag{18}$$

It now remains to represent w_d' and w_c' in terms of temperature, voltage and line current so that, for assumed values of any two of these the other can be solved for.

The current and voltage vary over the length of line, therefore, the hot spot temperature will depend upon its position in the line. If it is at receiver end where the voltage and power factor are constant and independent of current the solution is simple, as load current only must be solved for. Thus, for assumed values of T';

$$w_d' = e_r^2 g_d \tag{19}$$

$$w_c' = I_r^2 r_c \tag{20}$$

combining (**18**), (**19**) and (**20**):

$$A' (T' - T_1) = e_r^2 g_d + I_r^2 r_c \tag{21}$$

in which I_r, being the only unknown, can be solved for.

If the hot spot is at distance l from receiver end the solution is more complicated, for line voltage, power factor and current all depend upon the general line characteristics, as shown, for example, in Table VII. Assuming that e_g and I_g are known, temperature T' can be solved for as follows:

The empirical formula for g_d, found by the $\Sigma\triangle$ method, takes the form;

$$g_d = B + D\,(T')^n \tag{22}$$

where B, D and n are constants;

$$\therefore w_d' = e_g^2\,[B + D\,(T')^n] \tag{23}$$

From formulas (**6**)[14] and (**20**);

$$w_c' = I_g^2\,\{r_{25}\,[1 + .00378\,(T' - 25)]\} \tag{24}$$

combining (**18**), (**23**) and (**24**)

$$A'\,(T' - T_1) = e_g^2\,[B + D\,(T')^n] + I_g^2\,\{r_{25}\,[1 + 0.00378\,(T' - 25)]\} \tag{25}$$

in which T' being the only unknown can be solved for.

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[14] Formula (6) does not apply when single-conductor cable with short circuited sheath is used. In that case a modification of Formula (2) in Appendix B, for r_{eff} must be used.

To be presented at the 35th Annual Convention of
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Lake Placid Club, N. Y., June 27, 1919.

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(*Subject to final revision for the Transactions.*)

THE EFFECT OF TRANSIENT VOLTAGES ON DIELECTRICS II

The Effect of Lightning Voltages on Arrester Gaps, Insulators and Bushings on Transmission Lines

BY F. W. PEEK, JR.

Abstract of Paper

This paper treats of some of the practical applications resulting from an investigation of the effect of lightning voltages on insulators, bushings and protective gaps.

There is a great difference in the relative lightning spark-over voltages of various gaps as well as a great difference in the settings imposed by operating conditions. Both of these factors must be considered in comparing the relative protective values.

A gap must be set so that the normal line voltage does not cause it to spark-over. Gaps are generally used out of doors. Rain lowers the 60-cycle spark-over voltage of all uncovered gaps and thus imposes a greatly increased setting and decreased protective value since the lightning spark-over voltage is not changed by rain.

The covered sphere gives the maximum protection. The protective value is constant under all conditions.

The sphere-horn, having electrodes of points, horns and spheres, gives very good protection over the whole range of frequency and wave front. The spheres discharge the very steep waves, the horns the moderate ones, and the points continuous high-frequency waves of slanting front and static.

The protective value of selective gaps varies with the wave front. Its protective value is a minimum for very steep wave fronts and for waves of slanting front. Over a certain range its protective value is very good.

The relative protective values of various gaps for steep and slanting wave fronts and high frequency are shown graphically in Figs. 14, 15, 16 and 17. The relative protective values are approximately independent of the point on the 60-cycle wave at which the discharge occurs.

Data are given on the steepness of lightning waves actually occurring on transmission lines in practise.

Bushings and insulators with equal 60-cycle spark-over voltages may have entirely different lightning spark-over voltages. A bushing should be designed for a high lightning spark-over voltage.

The lightning wet spark-over voltage of a bushing or insulator is the same as the dry spark-over voltage.

IN 1915 I presented a paper covering an extensive investigation on the effects of transient or lightning voltages on air, oil and solid insulations, line insulators and the discharge voltages of various gaps.[1] An exact study was made possible

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Manuscript of this paper was received April 25, 1919.

by the development of the "impulse generator," which was also described in the paper referred to above, and as a result some very important fundamental relations were discovered.

It is the purpose of this paper to treat in more detail a few of the important practical applications which have been made of these relations within the last few years. The present discussion will be concerned principally with lightning arrester gaps, bushings and line insulators. It is hoped in particular, to make clear the advantages and disadvantages from a strictly practical standpoint of the various arrester gaps.

The fundamental relations referred to above, bearing on the present discussion, will be briefly reviewed:

When a 60-cycle voltage is slowly applied to a gap and gradually increased, spark-over will occur at some definite voltage. This is the minimum voltage that will cause sufficient ionization for the gap to discharge and it requires a relatively long time.

Lightning voltages, or voltages of relatively steep wave front start at zero or line voltage and increase at the very rapid rate of millions or billions of volts per second. When such voltages are applied across a gap or insulator, spark-over does not occur at the instant the minimum or 60-cycle voltage is reached, as considerable time is required at this voltage. When this voltage is reached the spark begins to form but is only completed after the rapidly rising voltage has reached some higher value. The "slower" the gap the higher the voltage will rise. In a uniform field, break-down takes place over a relatively short path, everywhere, at the same time. In the case of a non-uniform field represented, for instance, by the needle gap, corona forms around the electrodes before spark-over. A vast amount of air must be ionized. The condition is equivalent to putting the corona or arc resistance in series with an ever increasing capacity represented by the unbroken dielectric. Time is thus required to bring all of the space between the electrodes up to the break-down gradient and during this time, the lightning voltage rises higher and higher.

To summarize: (1) Two gaps or insuatorsl with equal 60-cycle spark-over voltages may have entirely different lightning or impulse spark over voltages because of the time lag.

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1. "The Effect of Transient Voltages on Dielectrics," F. W. Peek, Jr., A. I. E. E., Vol. XXXIV, 1915, page 1857.

"Lightning," *General Electric Review*, July 1916.

(2) The time lag is the greatest in a non-uniform field or for electrodes where corona precedes spark-over; it is minimum for a uniform field.

(3) The time lag for any given electrodes and spacing is not constant, but depends upon the steepness of the wave or the rate at which the voltage is applied. The spark-over voltage increases and the time lag decreases with increasing steepness of wave front.

(4) Lightning or impulse spark-over voltages, unlike 60-cycle spark-over voltages, are not appreciably lowered by rain.

The above discussion means, of course, that certain gaps and insulators which have equal 60-cycle spark-over voltages may have entirely different lightning spark-over voltages. The ratio between the impulse and 60 cycle spark-over voltage was termed the impulse ratio. When there is no time lag the impulse ratio is unity; the greater the time lag, the higher the impulse ratio. Under certain conditions selective gaps may have an *apparent* impulse ratio of less than unity.

It is very important to utilize these principles in design; protective gaps should have an impulse ratio of unity or low lightning spark-over voltage, while insulators and insulation should have a high impulse ratio or high lightning spark-over and puncture voltage.

The practical application of these principles to various protective gaps will first be discussed.

PROTECTIVE GAPS

General. The lower the voltage at which a given arrester gap can be set the greater is its protective value. In practise, the setting must be such that the gap does not discharge under any normal operating condition. The 60-cycle spark-over voltage of a gap is very much decreased if the electrodes become wet. The decrease in voltage due to moisture differs greatly with the shape of electrodes. It is minimum for points and maximum for plane surfaces. The 60-cycle spark-over voltage of a gap may be affected by other surface conditions, but by far the greatest effect is that caused by moisture. See Table I. Practically all high voltage arrester gaps are installed out of doors. These gaps must, therefore, be set so that the line voltage does not cause spark-over during a rain storm. This means that with any gap with "fast" electrodes the setting must be approximately doubled and the protective value thus reduced.

The wet and dry 60-cycle spark-over voltages of 6.25 cm. spheres is given in Fig. 1. That the lightning spark-over voltage is not appreciably changed by rain is shown in Fig. 2. In comparing the relative protective value of lightning arrester gaps it is, thus important to make the comparison on equal wet 60-cycle spark-over voltages or by the setting imposed by the operating conditions.

TABLE I

SPHERE GAP

The Approximate Effect of Rain, Ice, Dust, etc. on the 60 Cycle Spark-over Voltage of Sphere Gap.

Foreign material on sphere surface.	Voltage per cent of normal
Thin coating of dust	98
Coating of oil	100
Heavy coating of oil and sand	75 - 90
Thin coating of ice	75 - 90
Thick coating of ice	75 - 80
Surface oxidized	100
Ordinary pitting	90 - 100
Rain 0.2 in. precipitation per min. Polished spheres	40 - 50
Rain 0.2 in. precipitation per min. Pitted spheres	40 - 50

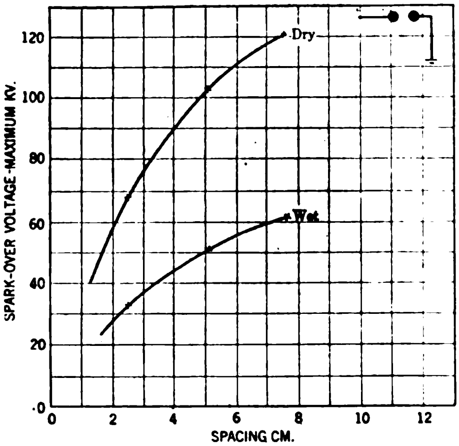

FIG. 1—SPHERES—WET AND DRY SPARK-OVER VOLTAGES

6.25 cm. spheres—60 cycles—one sphere grounded—0.2 in. rain—data Table II

Operating conditions other than rain or inherent properties of the arrester proper may make it necessary to increase the setting of certain types of gaps and not of others. Rain is, however, the chief factor in non-selective gaps. As an example of the effect of rain on the setting, assume a 66,000-volt line with grounded neutral. The voltage to ground is

$$\frac{66{,}000}{1.73} = 38{,}000$$

The arrester gap must be set at about 25 per cent above this or 47 kv. wet. Referring to Fig. 2, if the gap is protected from the weather the lightning spark-over voltage is 47 kv., wet or dry; if the gap is not protected from the weather the dry 60-cycle spark-over voltage must be 94 kv. in order to make the wet 60-cycle spark-over voltage 47 kv. and the apparatus is thus subjected to double the stress which would obtain if a covered gap were used. This follows because the lightning spark-over voltage approximately corresponds to the dry setting. There may be no gain in protection with a gap discharging at very low lightning voltages if in practise it must be set at a wide spacing to prevent line voltages from continually causing it to spark over.

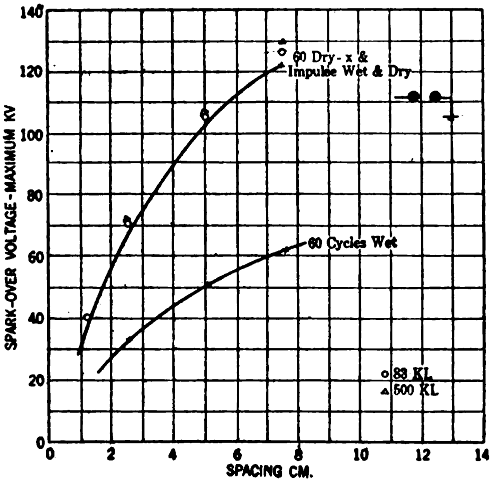

FIG. 2—SPHERE—WET AND DRY SPARK-OVER VOLTAGES
6.25 cm. spheres—60 cycles and impulses—0.2 in. rain—one sphere grounded—data Table II

The horn gap is not affected by the weather to as great an extent as the sphere gap. If a sphere and a horn are adjusted for equal wet 60-cycle spark-over voltages, the dry 60-cycle spark-over voltage of the horn will be lower. For low-frequency surges the horn would thus discharge at a lower voltage. For steep wave front lightning voltages however, the lag of the horn, which may easily have an impulse ratio of 2, will cause it to give inferior protection. See Fig. 3.

THE SPHERE GAP—THE SPHERE HORN

The sphere gap has an impulse ratio of unity. It thus offers equal protection for all sorts of transient voltages, and is without time lag when set at not greater than diameter spacing. When exposed to the weather, however, the setting must be high enough so that the line voltage will not spark-over during rain. See Figs. 1 and 2.

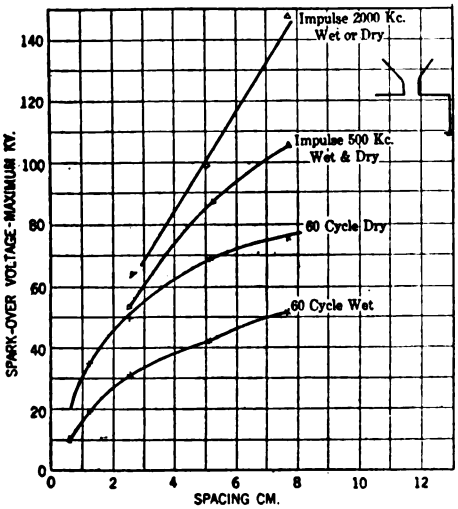

FIG. 3—HORNS—WET AND DRY SPARK-OVER VOLTAGES

60-cycle and impulse—wet and dry—data Table IV

In the practical gap the sphere and horn were combined; the horn being used to assist in breaking the dynamic arc and for the gain in discharging low-frequency surges due to the smaller difference between the wet and dry spark-over voltages. The difference between the wet and dry spark-over voltage of points is less than with the horn. A point is sometimes added to further increase the protection at low-frequency surges.

This gap has proved very successful in its several years of practical use, very greatly increasing the protective value of arresters. See Fig. 4. Take for comparison equal wet settings of 50 kv. at 2000 kilocycles the spark-over voltage of the horn is 135, the sphere 100. For impulses below 500 kilocycles, the spark-over voltage of the horn is lower than the sphere. Thus, when a sphere horn is used the discharge takes place across the sphere for steep wave fronts and across the horn for low-frequency surges. The gain due to the sphere is greater at higher voltages and steeper wave fronts. The covered gap, shown by the dotted line is superior at all wave fronts.

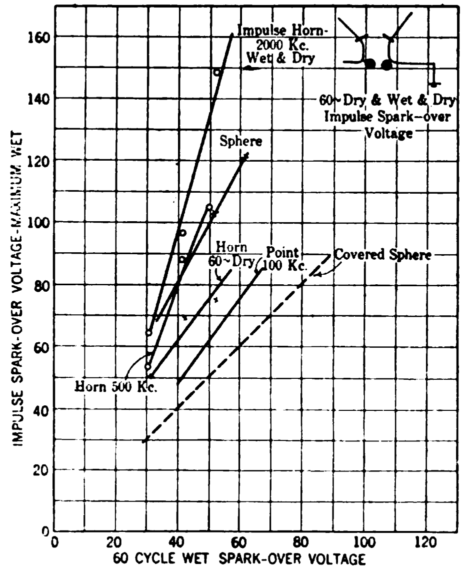

FIG. 4—SPHERE—HORN

Relative protective values of the component parts—data Tables II, IV, and V

The Covered Sphere. If a sphere gap is covered and shielded from the weather its protective value is greatly increased since the setting imposed by the condition that the normal line voltage must not discharge over the gap is cut in half. Such a gap, therefore, discharges lightning voltages of half the value of the uncovered sphere. This gap gives the highest degree of protection. It is not possible to use it with all types of arresters since a horn is often necessary to assist in breaking the dynamic arc. See Fig. 5. A properly designed hemisphere may also be used in this type of gap.

A gap not appreciably affected by the weather and still providing an arc breaking horn may be built as shown in Fig. 6. The way this accomplishes the desired results will be described later.

Since the gap requires two spheres in series, it is necessary to determine if such an arrangement has appreciable time lag and, therefore, high lightning-discharge voltages. Two 6.25-cm. spheres connected in series are shown in Fig. 7. If gap *A* is set at approximately 25 kv. and gap *B* at approximately 75 kv. the 60-cycle spark is not (25 + 75) = 100 kv. but is 75 kv.; the lightning or impulse spark-over is 91 kv. See Fig. 7.

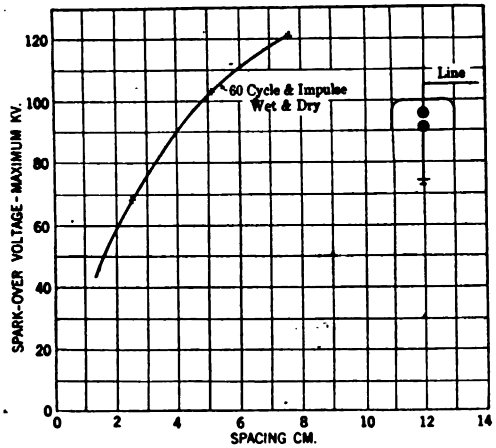

FIG. 5—SPHERES—WET AND DRY SPARK-OVER VOLTAGES

6.25 cm. spheres—covered gap—60 cycle and impulse—wet and dry—one sphere grounded—data Table V

The two gaps break down at 75 kv., 60 cycles, instead of the sum of the two or 100 kv. because the applied voltage does not divide evenly between them. The voltage reaches 25 kv. across the low-voltage gap and breaks that gap down before it reaches 75 kv. on the high-voltage gap. All of the stress is thus transferred to the high voltage gap and it breaks down as soon as a total voltage of 75 kv. is reached. If, now, capacities are adjusted across *A* and *B* so that the voltage divides in proportion to their relative break down voltages both gaps will break down simultaneously. The break down voltage will be equal to their sum. This is called the "balanced" gap. When two sphere gaps each without appreciable lag are placed in series it is found that unless the gaps are "balanced" there is considerable lag. This would be expected because one gap breaks down first and puts resistance in series with the capacity of the other similar to the corona in the needle gap. Balancing the gaps causes simultaneous spark-over and there is no appreciable lag. See Fig. 7.

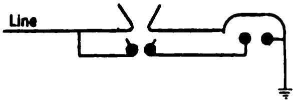

Fig. 6

If two gaps are placed in series as in Fig. 6 and balanced by properly adjusting their relative capacities there will be no appreciable lag. The rain affects only the outside gap. For example, if the outside gap is set at 10 kv. and the inside gap at 50 kv. the outside gap may be reduced to 5 kv. by rain. If balanced wet, the total wet spark-over is 55 kv. while the dry spark-over voltage is about 60 kv. This gap is thus without appreciable lag and not appreciably affected by rain. The only object of the outside gap is, of course, to transfer the dynamic arc to the horn where it rises and breaks.

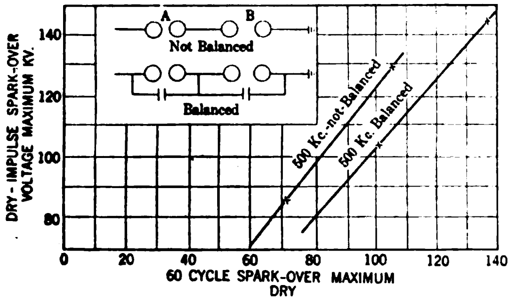

Fig. 7

Data Table III

The impulse and 60 cycle characteristics of this gap are shown in Fig. 8.

The advantage of the sphere gap is that it gives equal protection under voltages of all frequencies and wave front and is practically without lag.

Selective Gaps. Various forms of selective gaps have been proposed from time to time. Probably the most interesting and important of these is that investigated by Mr. Allcutt and shown in Fig. 9.[2] In this gap the division of voltage is not greatly affected at 60 cycles by the auxiliary electrode. The auxiliary electrode is held at mid-potential because it is connected at the mid-point between two equal condensers. The capacity current is too small at 60-cycles to cause any appreciable "drop" across the resistance. If the condenser circuit were opened on one side, the gap on that side would break down at about half voltage. This is exactly what happens under impulse.

For steep wave fronts the resistance has the effect of opening the condenser circuit on that side. See Fig. 10. The gap on that side breaks down. The voltage does not immediately disappear across the arc. The gap has lag for the same reason as the double unbalanced gap discussed above. Whether it is above or below the 60-cycle setting depends upon the impulse. The effect is similar to that which would result from a needle gap which could be set at, for instance, 100 kv. for 60-cycle operation and instantly and automatically reduced

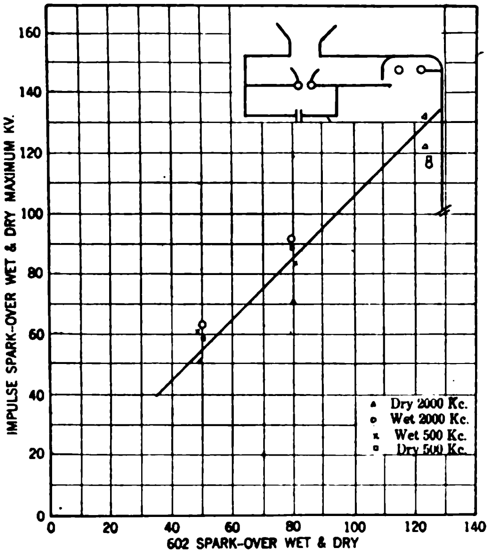

Fig. 8—Wet and Dry Spark-Over Covered Double Gap Balanced
Data Table VI

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[2] "Lightning Arrester Spark Gaps," C. T. Allcutt, A. I. E. E., May 1918.

Discussions F. W. Peek, Jr., A. I. E. E., Atlantic City, June 1918.

to a 50 kv., 60-cycle setting whenever an impulse came on the line. For moderately steep wave fronts the spark-over voltage would be greater than 50 and less than 100 kv.; but for very steep wave fronts, the impulse ratio of the 50 kv. gap would be greater than two, or the spark-over voltage would be greater than 100 kv. The impulse ratio of the selective gap is always greater than unity; the *"apparent" impulse ratio* is greater or less depending upon the steepness of the wave front. The reason this distinction is made is discussed elsewhere.[3] The apparent impulse ratio should be used in comparing protective values. This characteristic for the selective gap is shown in Fig. 11 and compared with a sphere gap for the same dry 60-cycle settings. The sphere gap spark-over voltage is practically constant for all wave fronts. The spark-over voltages are the same for 60 cycles. At moderate wave fronts the selective gap has about 5 to 20 per cent lower spark-over voltage than for spheres, while for steeper wave fronts the voltage is higher on the selective gap. The protective value of a gap, as already pointed out, depends not only on its lightning discharge voltage for a given 60-cycle setting, but also upon the setting which is imposed upon it by operating conditions. Fig. 11 shows the relative protective values of spheres and

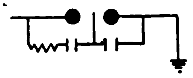

Fig. 9

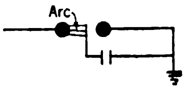

Fig. 10

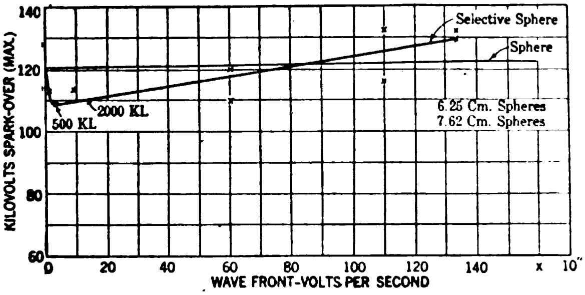

Fig. 11—Variation of Spark-Over Voltage with Wave Front—Sphere and Selective Sphere—
Data Table VII

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[3] A. I. E. E. Discussion, June 1918, F. W. Peek, Jr.

selective spheres assuming equal dry 60-cycle settings are possible. The settings must be such that the line voltage does not frequently spark-over and cause the destruction of the energy absorbing device under certain operating conditions. The effect of rain makes it necessary to set a non-shielded selective gap at about double the voltage that would be necessary in the protected gap. See Fig. 12.

Other forms of selective gaps have been devised and it is possible to extend the selective principle to a number of gaps in series, theoretically (neglecting lag) making it possible to discharge an impulse at a small fraction of line voltage. Such a gap would of course necessitate high initial setting and give very little protection against lightning impulses.

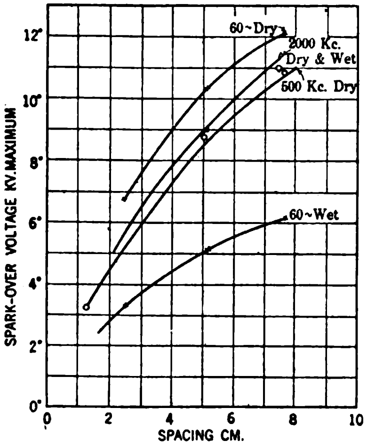

FIG. 12—SELECTIVE SPHERE

60-cycle and impulse—wet and dry—Data Table VIII

The selective principle may also be readily applied to covered gaps if it is deemed advisable.

RELATIVE PROTECTIVE VALUES OF THE GAPS ALREADY DISCUSSED

The following comparison of the different gaps is the result of extensive research. The tests were made with the impulse generator. The methods of conducting the tests, the precautions, accuracy, etc. are the same as discussed in the former paper.[4] For convenience the connection diagrams are shown in Fig. 13—(a) is used when the impulse only is applied to the gap; (b) when the impulse is superposed on the 60-cycle wave.

There are three cases which require consideration.[5]

Case A. Where the impulse occurs at the zero point of the 60-cycle wave and is thus not affected thereby.

Case B. Where the impulse occurs at the maximum of the 60-cycle wave and is additive.

Case C. Where the impulse occurs at the maximum of the 60-cycle voltage wave, but in the opposite direction.

Case C is naturally the most dangerous case. Case A is equivalent to applying the impulse without 60-cycle voltage.

In making impulse tests it is found that there is a certain minimum impulse voltage that will spark-over the gap only occasionally and that the voltage must be increased to cause spark-over at every application. This difference between minimum spark-over and spark-over at every application may be inappreciable for some gaps and quite appreciable for others. This is discussed in my former paper. It is, thus, obviously necessary to record the method of making the tests. The data for all of the curves with description of method of making measurements will be found in the tables. Unless otherwise stated, the impulse voltage was increased until the gap sparked once in five applications. "Frequency" is used for convenience only. It means, unless otherwise stated, that an impulse approximating a single half sine wave of the frequency stated has been used. By applying a super-voltage or a voltage higher than the discharge voltage of the gap the steepness of

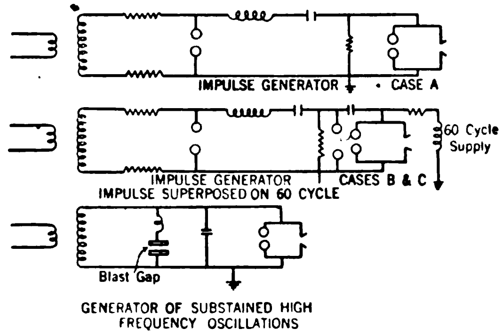
IMPULSE GENERATOR
CASE A
60 Cycle Supply
IMPULSE GENERATOR
CASES B & C
IMPULSE SUPERPOSED ON 60 CYCLE
Blast Gap
GENERATOR OF SUBSTAINED HIGH FREQUENCY OSCILLATIONS

FIG. 3—CONNECTIONS USED IN MAKING TESTS

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[4] "The Effect of Transient Voltages on Dielectrics," A. I. E. E., F. W. Peek, Jr., 1915.

[5] "Lightning Arrester Spark Gaps," C. T. Allcutt, A. I. E. E., May 1918. Discussion, F. W. Peek, Jr., A. I. E. E., June 1918.

the wave or rate of application is increased. For instance a super-voltage at 100 kilocycles might be steeper than a lower voltage at 2000 kilocycles. In making measurements by adjusting two gaps in parallel for equal spark-over, as is done in the case of super voltages, it is important to arrange the gaps symmetrically with equal length of leads; otherwise inconsistent results will be obtained. With steep waves and unsymmetrical leads it is possible to short-circuit one gap and still obtain sparks on the other.

The over-voltages that cause insulation failures in practise may be divided into three classes:

1. Gradual increase of voltage on the line due to static or low frequency surges.
2. Very high frequency oscillations of voltages generally too low for any gap arrester to discharge, but which may cause very high internal voltages in apparatus.
3. The form of voltage with which we are principally concerned—lightning voltages of very steep wave fronts where the voltage across the apparatus increases from normal to a very high value in perhaps a millionth of a second.

Condition. (1) is readily taken care of by any gap and need not be further discussed; (2) is of some interest but is a condition generally not taken care of by a gap arrester—some results of tests will be given however; (3) is the steep wave front condition that represents lightning proper and with which we are mostly concerned.

Relative Protective Value of the Horn, Sphere-horn, Selective Sphere Gap and Covered Gap.

Impulse Voltages of Steep Wave Front. The spark-over voltages of various types of gaps are plotted with equal wet 60-cycle settings in Fig. 14. Values are plotted for both wet and dry electrodes. The wave applied was a single half-cycle of a 2000 kilocycle wave with a 340-kv. maximum; that is, at super-voltage. The rate of application of voltage of the wave front was thus about 70×10^{11} volts per second. I believe that waves steeper than this occur on lines in practise. In fact, I first noted that there was a difference between the 60-cycle and lightning spark-over voltages of various electrodes by the existence of such waves on an operating line. The bushings on the line always protected the lightning arrester horns although the horns had a lower 60-cycle spark-over voltage. By measuring the impulse spark-over voltages of the bushing and the arrester gap in the laboratory it was found that the bushing protected the horn for a wave front at which the impulse ratio of the horn was over (2); this corresponds to a steeper wave than the one under immediate discussion.

It will be noted that the covered gaps give by far the best protection under this condition. For example, when all the gaps are set on the line at 100 kv., lightning voltage discharges respectively at 100 kv. on the covered gap, 115 kv. on the balanced covered gap, 225 kv. on the sphere of the sphere horn, 225 kv. on the selective sphere, and 320 kv. on a horn.

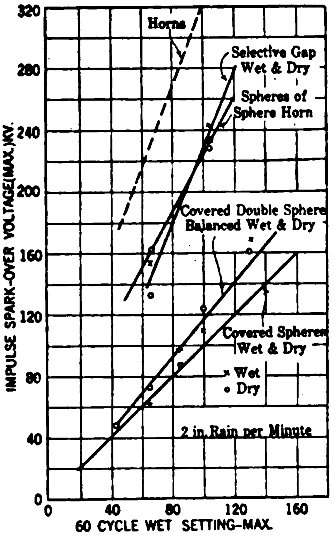

FIG. 14—RELATIVE PROTECTIVE VALUES OF HORNS, SPHERE-HORNS, SELECTIVE SPHERES. COVERED SPHERES—STEEP WAVE FRONTS

2000 kilocycles—340 kv.—impulse—data Tables IX, X and XI

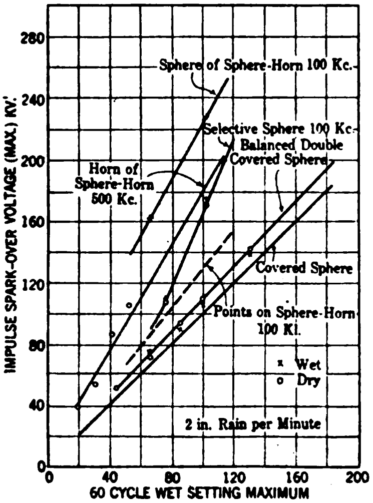

FIG. 15—RELATIVE PROTECTIVE VALUES OF SPHERE-HORN, SELECTIVE SPHERES, COVERED SPHERE—MODERATE WAVE FRONTS

Impulse—single half-cycle 100 kilocycles—non-grounded—data Tables IX, X and XI

Moderate Wave Fronts. A similar comparison is given in Fig. 15 for moderate wave fronts. The impulses being single half cycles of 100 kilocycle waves, the average fronts ranging from 0.5 to 1. × 10^{11} volts per second.

It will be noted that here, also, the covered spheres give the best protection. For example, at a 100-kv. line setting the impulse spark-over voltages are respectively 100 kv. for the covered sphere, 110 kv. for the balanced covered sphere, 170 kv. for the selective sphere, 178 kv. for a horn or the horn of the sphere horn, 130 kv. for points of the sphere-horn, and 222 kv. for the sphere. If this data is compared with that in Fig. 14 the value of the sphere horn combination is well illuslustrated. For the steep wave fronts the sphere affords the better protection, while for the moderate waves the horn affords the better protection and a still greater gain is made by adding points. This comes about, of course, due to the difference between the wet and dry setting.

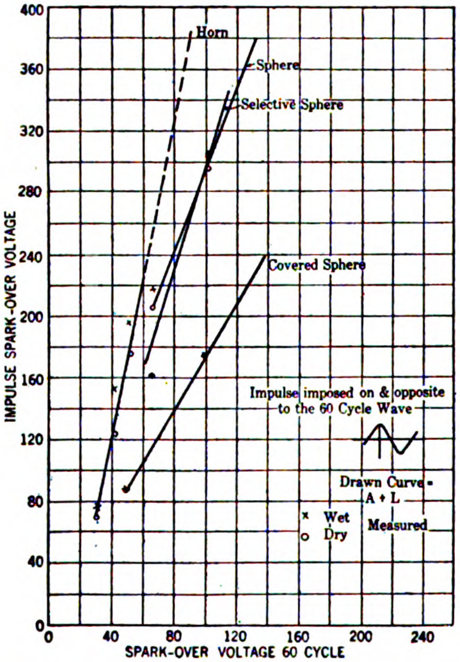

FIG. 16—RELATIVE PROTECTIVE VALUES OF VARIOUS GAPS

Impulses imposed on and opposite to the maximum of the 60-cycle wave—data Table XII

Ratio for Comparing the Relative Protective Value of Various Gaps. From the above discussion it is readily seen that in order to compare the relative protective value of various gaps two factors must be considered.

1. The increased 60-cycle setting imposed by operating conditions to prevent the gap from continuously discharging *due to rain or harmless surges*. Let the ratio of the actual operating setting to the normal setting be called α where the normal setting is the setting that just prevents the line voltage from arcing over under ideal conditions.

2. The impulse ratio (or apparent impulse ratio for the selective gap) for the wave under consideration. Let the impulse ratio be called β

The relative protective value of two gaps is then $\frac{\alpha_1 \beta_1}{\alpha_2 \beta_2}$.

For example:—a gap must be set at 50 kv. (max.) to prevent the 60-cycle line voltage from causing it to spark-over under ideal conditions. The relative protective values of a horn and a covered sphere for the 2000 kilocycle wave are obtained as follows from Figs. 3 and 5.

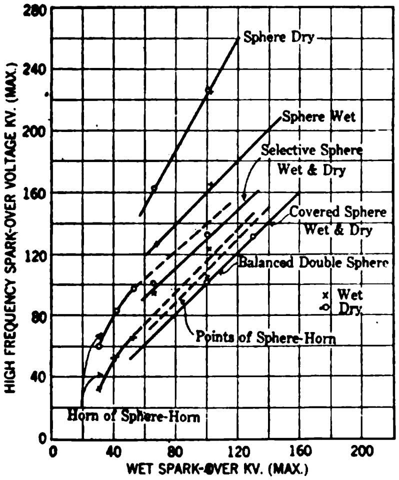

FIG. 17—RELATIVE DISCHARGE VALUES SPHERES, SELECTIVE SPHERES, COVERED SPHERES,—50,000 CYCLE SUSTAINED OSCILLATION—Data Table XIII

Horn	Covered Sphere
$\alpha_1 = 75/50 = 1.50$	$\alpha_2 = 50/50 = 1$
$\beta_1 = 133/75 = 1.77$	$\beta_2 = 50/50 = 1$
$\alpha_1 \beta_1 = 1.50 \times 1.77 = 2.65$	$\alpha_2 \beta_2 = 1$

$\alpha_1 \beta_1 / \alpha_2 \beta_2 = 2.65$

The horn permits the lightning voltage to rise to 2.65 times the value of the voltages permitted by the covered sphere.

Combination of Lightning and 60-cycle Voltages. The lightning spark-over voltage is a minimum when it occurs at the maximum of the 60-cycle wave and in an additive direction (case B). The lightning voltage is a maximum when it occurs at the maximum of the 60-cycle wave but in the opposite direction (Case C). The relative effects are approximately the same for all of the types of gaps discussed. If the lightning voltages for case A, Case B, Case C and the 60-cycle line voltage are called A, B, C and L respectively the lightning spark-over voltages are approximately:

Case A.................... A
Case B.................... $A - L$
Case C.................... $A + L$

Data for Case C are plotted in Fig. 16.

High Frequency Oscillations. The effect of sustained high frequency oscillations not very highly dampened is shown in Fig. 17. For connections see Fig. 13 (c). It is probably very rarely that oscillations with such a low damping factor occur on a transmission line. The arcing ground condition is more nearly approximated by a series of the impulses discussed above. Note that the horn and points give good protection for sustained oscillations.

LINE INSULATORS, BUSHINGS AND INSULATION

General. Line insulators and bushings should have a high impulse ratio or lightning arc-over voltage. The bushing mentioned above as protecting the horn had a low impulse ratio. The 60-cycle and lightning spark-over voltages were nearly equal. The horn would have given protection in this case if the impulse ratio had been higher. Bushings are now designed with a high impulse ratio.

The 60-cycle spark-over voltage of a bushing or insulator is often very appreciably lowered by rain. It is fortunate, however, that the lightning spark-over voltage is not appreciably changed by rain.

The data below were taken on different lengths of strings of Hewlett disk insulators. The impulse was a single half-cycle of a 200-kilocycle wave, or of very moderate wave front.

SPARK-OVER VOLTAGES—DISK INSULATORS
(One side Grounded—Dry)

No. of units	60-cycle spark-over	Impulse spark-over 200 kc.	Impulse ratio	String efficiency 60-cycle	String efficiency impulse 200 kc.
1	80	85	1.06	....	....
2	142	167	1.18	0.87	0.98
3	204	262	1.28	0.85	0.99
4	261	345	1.36	0.81	1.01
5	317	410	1.30	0.79	0.97
6	368	....	....	0.77	....

$$\text{String efficiency} = \frac{\text{Measured spark-over of string}}{\text{Number of units in string} \times \text{spark-over voltage of one unit}}$$

It is interesting to note that even with this moderately steep wave front the lightning spark-over voltage is approximately the product of the spark-over voltage of a single unit and the number of units in a string. The impulse voltage increases with increasing steepness of wave front.

The wet impulse spark-over voltage is approximately the same as the dry.

Impulse ratios of three or more have been obtained on bushings. More complete data on line insulators have been published elsewhere.[6]

CONCLUSIONS

1. There is a great difference in the relative lightning spark-over voltages of different gaps as well as a great difference in the settings imposed by operating conditions. Both of these factors must be considered in comparing the relative protective values. It is shown that if the lightning spark-over factor is represented by the impulse ratio β, and the setting factor by α, the relative protective value of two gaps are inversely as $\frac{\alpha_1 \beta_1}{\alpha_2 \beta_2}$.

2. β is due to time lag; α to the fact that the gap must be set so that the normal line voltage will not cause it to spark-over. Rain lowers the 60-cycle spark-over voltage of all gaps, and thus affects the ratio α. Rain does not lower the lightning spark-over voltage.

3. All uncovered gaps require a high setting factor, because rain lowers the spark-over value at 60 cycles. The effect is much less for points than it is for spheres.

4. The covered sphere gives better protection than any uncovered gap, because both α and β are low. The protective value is constant under all conditions.

5. The sphere-horn, having electrodes of points, horns, and spheres, gives very good protection over the whole range of frequency or wave front, due to the different values of α and β for its various electrodes. The spheres discharge the very steep waves, the horns the moderate ones, and the points continuous high frequency, waves of very slanting front and static.

6. The protective value of the selective gaps, as the name

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[6] "Factors Determining the Safe Spark-over voltage of Insulators and Bushings for High Voltage Transmission Lines," F. W. Peek, Jr., *General Electric Review*, June 1916.

implies, varies with the wave front. Its protective value is a minimum for very steep wave fronts, and for waves of slanting front. Over a certain range its protective value is very good.

7. The relative protective values of various gaps are shown in Figs. 14, 15 and 16.

8. The relative protective values of various gaps are approximately independent of the point on the 60-cycle wave at which the discharge occurs, as shown in Figs. 14, 15 and 16.

9. Data are given on the steepness of lightning waves actually occurring on transmission lines in practise.

10. Bushings and insulators with equal 60-cycle spark-over voltages may have entirely different lightning spark-over voltages. A bushing or insulator should be designed for a high impulse ratio or lightning spark-over voltage.

11. The lightning wet spark-over voltage of a bushing or insulator is the same as the dry spark-over voltage.

APPENDIX

TABLE II

SPHERE GAP

Wet and dry 60-cycle and impulse spark-over.
6.25-cm. spheres—One grounded 2 in. rain per minute.

Spacing		Spark-over voltage (maximum)			
Inch	Cm.	60-cycle and impulse dry	60-cycle wet	Impulse 83 kc. wet	Impulse 500 kc. wet
0.5	1.27			40	
1.	2.54	68	33	71	72
2.	5.08	103	51	105	106
3.	7.62	121	61	126	130
CASE B Impulse assisting and at maximum of 60-cyce wave.					
		Impulse dry 500 kc.			
1	2.54	52			
2	5.08	60.5			
3	7.62	86			
CASE C Impulse opposing and at maximum of the 60-cycle wave.					
1	2.54	108			
2	5.08	148			
3	7.62	160			

No parallel gap—one discharge in five applications 60-cycle voltage ½ dry discharge voltage of the gap in cases B and C.

TABLE III
60-CYCLE AND IMPULSE SPARK-OVER OF TWO GAPS IN SERIES.

6.25-cm. spheres.
One sphere grounded.

Spacing gap				60 cycle spark-over				Impulse spark-over	Impulse ratio
A		B		A	B	Sum A and B	Measured A and B	500 kc.	
Inch	Cm.	Inch	Cm.						
		Gaps not balanced for simultaneous spark-over							
0.45	1.19	1.02	2.59	35	68	103	72	86	1.20
0.45	1.19	2.15	5.46	33.7	107	140	106	129	1.21
		Gaps balanced for simultaneous spark-over							
0.45	1.19	1.02	2.59	35	67	102	101	103	1.02
0.45	1.19	2.15	5.46	33.7	107	140	136	144	1.06

Impulse voltages applied and increased in values until one spark-over occurred in five applications. No. 60 cycle voltage on the gap.

TABLE IV
HORNS

Wet and dry 60-cycle and impulse spark-over
Voltage of horns (3/8 in.)
0.2 in. rain—one horn grounded.

Spacing		Spark-over voltage—maximum					
		Dry			Wet		
Inch	Cm.	60 cycle	500 kc.	2000 kc.	60 cycle	500 kc.	2000 kc.
0.25	0.63	19	....	....	9.2	....	....
0.5	1.27	35	39.7	44.5	19.7	....	....
1	2.54	50	53	63.5	31.0	....	45
2	5.08	69	88	96.5	41.5	....	99
3	7.62	74.5	105	148	52	117	148

No parallel gap.—One discharge in five applications. 2000 kc (b) wave Table XIV.

TABLE V
COVERED SPHERES
Wet and Dry—60-cycle and Impulse Spark-over Voltage
6.25-cm. spheres—One sphere grounded.

Spacing		Spark-over Voltage—Maximum					
Inches	Cm.	60 cycles dry	500 kc. dry	2000 kc. dry	60 cycles wet	500 kc. wet	2000 kc. wet
Case A—No. 60-cycle voltage on the gap.							
0.50	1.27	....	....	....	....	....	....
1.00	2.54	68	68	68	68	68	68
2.0	5.08	103	103	103	103	103	103
3.0	7.62	121	121	121	121	121	121
Case B—Impulse assisting and at maximum of the 60 cycle voltage.							
1	2.54	....	52	....	....	....	....
2	5.08	....	60.5	....	....	....	....
3	7.62	....	86	....	....	....	....
Case C—Impulse opposed to and at maximum of the 60 cycle voltage.							
1	2.54	....	108	....	....	....	....
2	5.08	....	148	....	....	....	....
3	7.62	....	160	....	....	....	....

No parallel gap—One discharge in five applications—60 cycle voltage ½ dry discharge voltage of the gap applied in cases B and C. 2000 kc (b) wave Table XIV.

TABLE VI
Double Covered Sphere Gap—Balanced
Balanced Wet
(0.2 in. Rain—6.25-cm. spheres—One sphere grounded)

Total 60-cycle spark over max.	Gap setting Kv.max. dry		Impulse spark over total kv. max.	
			Wet	Wet
	A	B	500 kc.	2000 kc.
50	14	42	59	63
79	23.5	71	89	91
124	35	105	118	117
			Dry	Dry
48	14	42	61	51
80	23.5	71	83	71
123	35	105	132	122

Average measured voltages. 2000 kc (b) wave Table XIV.

TABLE VII
SELECTIVE SPHERE-HORN

(6.25-cm. Spheres with Auxiliary Electrode). One side grounded.

Gap setting		60-cycle spark-over kv max.	60-cycle spark-over ½ gap kv. max.	Impulse spark-over total gap	Apparent impulse ratio	Impulse ratio
In.	Cm.					
		Single half cycle 83 kilocycles				
½	1.27	38	23	28	0.74	1.21
2	5.08	105	67	81	0.77	1.20
3	7.62	121	88	113	0.94	1.29
		Single half cycle 500 kilocycles				
½	1.27	38	23	32	0.84	1.40
2	5.08	105	67	87	0.83	1.30
3	7.62	121	88	109	0.90	1.24
		Single half cycle 2000 kilocycles (a) wave				
½	1.27	38	23	34	0.90	1.48
3	7.62	121	88	114	0.94	1.30
				Impulse spark-over total gap	Apparent impulse ratio	Wave front volts sec.
3	7.62	121	88	113	0.94	0.4×10^{11}
3	7.62	121	88	109	0.90	2.1×10^{11}
3	7.62	121	88	114	0.94	9.1×10^{11}
3	7.62	121	88	110–120*	.91–1.00	60×10^{11}
3	7.62	121	88	106–133*	0.88–1.10	110×10^{11}
3	7.62	121	88	130–132*	1.07–1.10	133×10^{11}

Above data for Case A—Impulse applied at zero of 60 cycle wave.
(*Range of equal spark-over.—Super Voltages, (b) wave Table XIV.)

TABLE VIII

SELECTIVE SPHERES

Wet and Dry 60-cycle and Impulse spark-over 6.25-cm sphere—One Grounded
0.2 in. Rain per minute

Case A							
Spacing		60-cycle spark-over Kv. max.		Impulse spark-over kv. max.			
				Dry		Wet	
Inches	Cm.	Dry	Wet	500 kc.	2000 kc.	500 kc.	2000 kc.
0.5	1.27	....	....	32	34	....	....
1	2.54	68	33	49	....	41	48.5
2	5.08	103	51	87	....	74	89
3	7.62	121	61	109	114	104	113
Case B—Impulse assisting and at the maximum of the 60-cycle wave.							
1	2.54	....	....	54	....	....	....
2	5.08	....	....	54	....	....	....
3	7.62	....	....	67	....	....	....
Case C—Impulse opposing and at max. of 60-cycle wave.							
1	2.54	....	....	97	....	....	....
2	5.08	....	....	115	....	....	....
3	7.62	....	....	147	....	....	....

Applied 60-cycle voltage ½ dry 60-cycle voltage of the gap and impulse one discharge in five applications. (2000 kc (a) wave Table XIV.)

TABLE IX

SELECTIVE SPHERES

12.5-cm. Spheres—Non-Grounded Impulses
Case—A

Setting		60-cycles spark-over Kv. (max.)		Impulse 2000 kc. 340 kv. (max.)		Spark-over 100 kc. single-half cycle.	
Inches	Cm.	Dry	Wet	Dry	Wet	Dry	Wet
2.80	7.10	162	66	133	153	107	109
5.34	13.5	227	102	233	242	170	174

Super Voltage Impulses measured at equal spark-over. 2000 kc (b) wave.

TABLE X
COVERED DOUBLE SPHERE GAP—BALANCED
7.6-cm. spheres—Non-grounded

Total 60-cycle spark-over kv. (max.)		Setting—60-cycles kv. (max.)				Impulse spark-over kv. max.			
						2000 kc. 340 kv.		100 kc.	
Dry	Wet	Outside dry	Outside wet	Inside dry	Sum wet	Dry	Wet	Dry	Wet
....	130	63.0	34	101	136	160	168	142	138
....	100	51.0	25.3	75	100.2	123	109	109	105
....	85	38.3	19.8	61	80.8	85.5	96.7	93	88
....	65.5	29.6	....	49.6	....	71	62	71	73
....	44	14.1	....	31.1	....	46.5	46.5	50.5	....

Super-voltage impulses measured at equal spark-over. (2000 kc (b) wave Table XIV.)

TABLE XI
SPHERES—IMPULSES
12.5-cm. Spheres—Non-grounded

Spacing		Spark-over kv. max.		Impulse Spark-over voltage kv. max.			
				(2000 kc.) 340 kv. max.		100 kc.	
Inch	Cm.	60-cycle Dry	60-cycle Wet	Dry	Wet	Dry	Wet
2.80	7.10	162	66	164	....	162	....
5.34	13.5	227	102	227	227	....	....

Super-voltage impulses measured at equal spark-over.
2000 kc (b) wave Table XIV.

TABLE XII

IMPULSE SPARK-OVER VOLTAGES WHEN THE 60-CYCLE LINE VOLTAGE IS ON THE GAP.—CASE C.

Spacing		60-cycle spark-over		Applied 60-cycle	Impulse spark-over kv. max. 2000 kc.					
Inches	Cm.	Kv. max.		Kv.	Case A No. 60-cycle		Sum A & L.		Case C measured impulse	
		Dry	Wet	L.	Dry	Wet	Dry	Wet	Dry	Wet
Selective spheres 12.5-cm.										
2.80	7.10	162	66	50	138	135	188	185	160	161
5.34	13.5	227	102	76.5	227	....	303	303	296	305
Spheres 12.5 cm.										
2.80	7.10	162	66	50	....	164	214	....	204	217
5.34	13.5	227	102	76.5	227	227	303	303	305	305
Covered Spheres 6.25-cm.										
0.70	1.8	50	50	37.5	50	50	87.5	87.5	87.5	87.5
1.58	4.0	100	100	75	100	100	175	175	175	175
Horns										
1	2.54	51	30.7	23	58.5	60	81.5	83	69	76
2	5.08	40.6	67.5	30.5	105	110	135.5	140.5	124	153
3	7.62	52	75	39	145	150	184	189	175	196

Case C—Impulse applied opposed to the maximum of the 60-cycle wave.
Applied 60-cycle kv. 75 per cent of wet 60-cycle spark-over.
Gaps not grounded. One discharge in five impulses.
2000 kc (b) wave Table XIV.

TABLE XIII
SPARK OVER VOLTAGES OF GAPS FOR SUSTAINED HIGH FREQUENCY OSCILLATIONS.

Gap-setting		Frequency of oscillations—Spark-over kv. max.									
Inches	Cm.	19,600		50,000		100,000		200,000		160,000 from high freq. coil	
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Selective Spheres 12.5-cm.											
2.80	7.10	112	105	100	95	77	90	77	92	108	125
5.34	13.5	200	143	131	123	126	127	120	122	170	186
Spheres 12.5 cm.											
2.80	7.10	162	106	162	126	163	106	162	118	163	....
5.34	13.5	227	173	227	164	12.27	173	227	169	227	....
Double gap—Balanced—Covered											
Setting Kv.-60 cycles Wet											
	100	....	98	....	105	....	102	93	100	112	112
	130	....	107	....	126	....	128	132	124	147	150
Covered Spheres											
....	50	50	50	....	....	....	50	50	50	50	50
....	100	100	100	....	....	....	100	100	100	100	100
Inches	Cm.	Horns									
1	2.54	....	....	58	33.5	....	....	....	....	....	....
2	5.08	....	....	82	54	....	....	....	....	....	....
3	7.62	....	....	97	67	....	....	....	....	....	....
Points											
1	2.54	....	....	28.5	28.5	....	....	....	....	....	....
2	5.08	....	....	46	46	....	....	....	....	....	....
3	7.62	....	....	64	64	....	....	....	....	....	....
4	10.2	....	....	74	74	....	....	....	....	....	....
5	12.7	....	....	88	88	....	....	....	....	....	....

TABLE XIV
IMPULSE GENERATOR CONSTANTS

Impulse	Wave	Capacity farads	Inductance henrys	Resistance
83	Single Half Cycle—Sine	1.25×10^{-9}	3.73×10^{-3}	1000
100	Single Half Cycle—Sine	1.25×10^{-9}	3.73×10^{-3}	2000
500	Single Half Cycle—Sine	0.62×10^{-9}	0.28×10^{-3}	750
2000	Single half Sine (a)	0.625×10^{-9}	3.34×10^{-5}	450
2300	(b) wave	1.25×10^{-9}	8.7×10^{-5}	3000

To be presented at the 35th Annual Convention of
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GROUNDING THE NEUTRAL OF GENERATING AND TRANSMISSION SYSTEMS

BY H. R. WOODROW

Abstract of Paper

Four different high-tension transmission systems in the New York district have been grounded at different times during the past four years, all of which are operating with the grounded neutral at the present time. These systems were all grounded in a different manner and the results obtained from the effect of grounding showed that the troubles have been reduced.

In addition to the grounding, special ground relays have been installed on three of the systems which disconnected the feeder very quickly on a ground and the results show that the addition of this quick acting relay further reduces the stresses on a system.

6600-Volt 25-Cycle System

It had been the policy of The New York Edison Company to operate its high-tension feeders radially with the system neutral ungrounded, but with selective ground indicating relays on all feeders to locate a ground on any feeder. This method of operation gave the operators time to disconnect defective grounded feeders from the system before developing into short circuits, and as a result 70 to 80 per cent of the system ground failures were cleared in this way.

During the later years, however, it became desirable to study means of paralleling feeders at the substations and of reducing the time limit for disconnecting the defective feeder to avoid short circuits following a ground on account of the increased capacity current of the greatly larger mileage of cables on the system.

After a careful analysis it was decided to establish a definite ground current by means of grounding transformers connected to the system bus and connect the selective ground relays to trip the oil circuit breakers automatically.

The method of grounding through zig zag-connected transformers was adopted as the latest generators installed are delta-connected, from which a neutral cannot be brought out. The limiting resistances were connected in the primary side

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of the grounding transformer and of a value to limit the total ground current with both generating stations operating in parallel to 400 amperes. The selective ground relays, which are operated from sheath type current transformers, are adjusted for operation on 140 amperes minimum and on 300 amperes in one second.

The above described system was placed in operation in the early part of 1918 and the accompanying Fig. 1 will show the results which have been obtained. Although the time that this system has been grounded is too limited to draw any definite conclusion, the total system troubles have slightly decreased and of these total troubles the number which have developed into short circuits is reduced to 60 per cent of those before grounding.

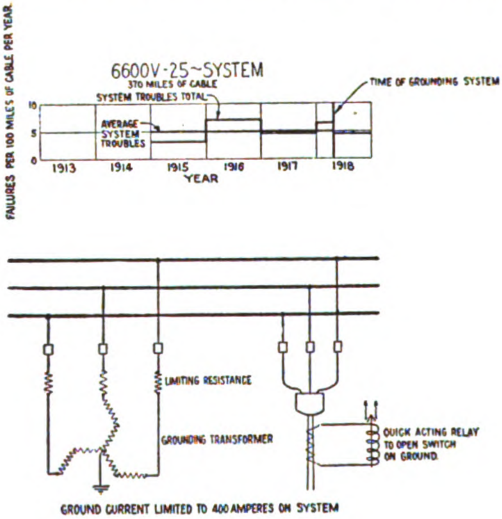

FIG. 1

7800-VOLT 60-CYCLE SYSTEM

The new 201st Street station of the United Electric Light & Power Company was placed in service with the same general scheme of operating with an ungrounded neutral with selective ground indicating relays. In the first few years of operation, however, several generator failures were experienced and at the recommendation of the manufacturer the system was grounded by means of the generator neutral through a two-ohm resistance, which would allow a ground current of approximately 2000 amperes to flow.

The results of the system troubles before and after grounding are shown in Fig. 2, and although no general system disturbances were experienced before the grounding, there has been an apparent reduction in the number of system troubles since grounding.

16,000-Volt System

When the 16,000-volt system was adopted for supplying the northern territory of the 25- and 60-cycle systems, step-up and step-down transformers were provided on each feeder, thereby isolating the high-tension side of each feeder. During the first two years of operation the number of cable failures was very large, most of which occurred in the cable splices.

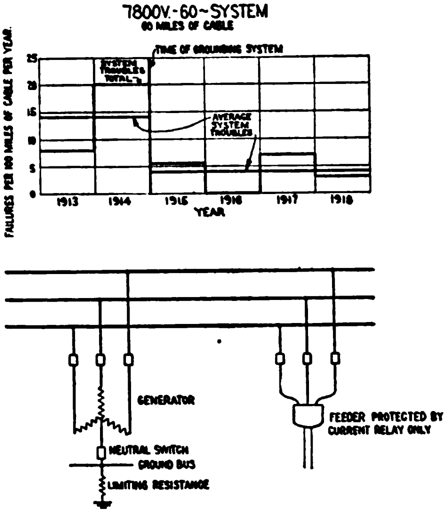

Fig. 2

To remedy this trouble a number of splices on the 60-cycle system were changed and the transformer connections were changed on both the 25-cycle and 60-cycle systems to make a solid ground on the high-tension side. The systems were operated in this manner for a period of approximately two years and no material change in the number of failures occurred. During this time, every ground on the system was a short circuit due to the solidly connected neutral, thereby materially increasing the stresses on the transformers and cables. It was decided to change the method of grounding and provide quick-acting relays to disconnect a feeder practically instantaneously on a ground.

The method adopted for grounding these feeders as shown in Fig. 3 followed the suggestion of Dr. Creighton of using potential transformers with the neutral grounded and the secondaries connected in delta with a quick-acting relay in the loop.

In the year and a half that this system has been in operation, the results have been encouraging although the number of system troubles, as shown in Fig. 3, was only reduced by approximately 28 per cent; the number of short circuits have been reduced by 82 per cent. In 73 per cent of the cases in the present method of operation the failures are disconnected from the system before short circuit occurs.

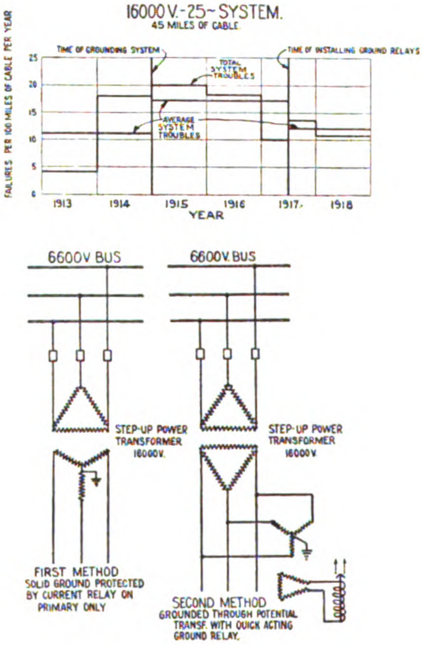

Fig. 3

These figures are the results on the 25-cycle system only, as a number of changes in the cable joints have been made on the 60-cycle cables and the results would be confused as it would be impossible to determine what portion was due to betterment of insulation and that due to the method of grounding.

25,000-Volt 25-Cycle System

In the installation of 25,000-volt 25-cycle cables, the neutral of the transformers at the generator end was solidly grounded.

The type of joint used in this cable was of the oil-filled type as described by Mr. Torchio before the Institute, and practically no failures have resulted in the splices. In the first fifteen months of operation, however, a number of cable failures occurred, some of which could be traced to defective manufacture of cable. To relieve the stresses on these cables it was decided to install grounding relays connected to a sheath transformer for disconnecting the cable very quickly on a ground, as the method of operation of these feeders necessitated a long time setting on the normal current relays.

These cables have been in operation with this method of protection for three years and, as shown in Fig. 4, the number of failures has decreased until no failures have occurred during the past year.

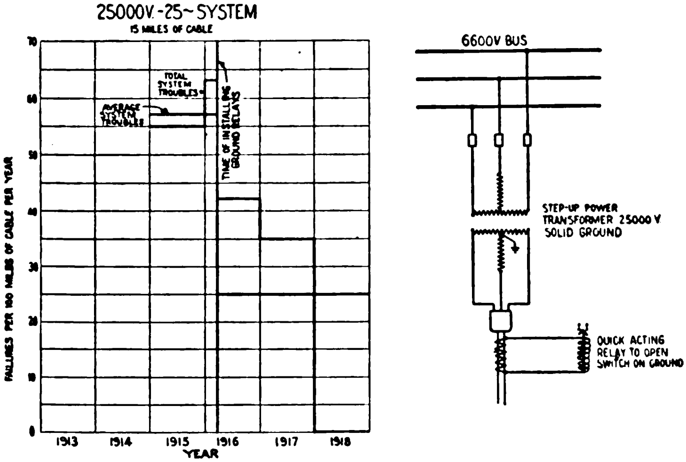

FIG. 4

CONCLUSION

Our experience has shown unquestionably that the stresses on the cables are relieved materially by grounding, but we further believe that it is desirable to limit this grounding current as much as possible, thereby reducing the stresses on the system and particularly the burning of lead sheath and grounding connections. Also the installation of grounding relays, which can be set to disconnect a feeder more quickly than the straight normal current relays, will further greatly relieve the potential stresses due to a prolonged grounding current which occur even with a grounded system.

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PROBLEMS OF 220-KV. POWER TRANSMISSION

BY A. E. SILVER

ABSTRACT OF PAPER

The dependence of industrial progress upon an adequate supply of electrical power, together with the vital need for a rational policy of conservation of the country's fuel resources, points to a probable early demand for transmission of large blocks of power from distant energy sources—coal fields and water powers. Two hundred and twenty kv. is suggested as a logical voltage for such high-capacity, long-distance transmission, and the important problems introduced by large concentrations of power, high voltage and high service standards are discussed. The economic and technical considerations underlying design of a 220-kv. system are outlined, and general designs are developed for a typical 220-kv. transmission line.

The studies made establish confidence in the conclusion that 220-kv. transmission is feasible as an immediate commercial proposition. Established principles of design and present types of equipment, with proper adaptation to the new conditions, are applicable to 220-kv. service. While all essential problems seem assured of acceptable solution, attention is directed to certain points as to which further investigation and experimental research are needed to determine most effective designs.

It is hoped that the paper may in some measure aid in the working out of this advance in the art by promoting constructive discussion and stimulating the needed investigations.

INTRODUCTORY

ECONOMIC development of the country's power resources is fundamental to the industrial progress of our national life. The growing recognition by our economists, engineers and industrial leaders, and even by the public, of the significance of the power supply problem must soon result in an insistent demand upon the engineering profession for large and bold strides in the solution of the attendant engineering problems.

The vital dependence of industrial advancement upon an adequate power supply has been strikingly illustrated in our struggles to meet the industrial demands of the war emergency. The experiences of this trying period have resulted, also in a quickened understanding of the need for conservation of our natural power resources. The labor and commodity situation

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accentuates the demand for greater unit productiveness, possible only through greater use of power in industrial operations, and for prompt progress toward broadly economical methods of power supply. A major step toward conservation of fuel resources and general commercial economy is recognized to lie in gradual substitution of electric transmission of energy for railroad transportation of fuel to be used in local generation of power. Interconnection of electric power systems, both prior to and during the war, has demonstrated the marked benefits obtainable by taking advantage of diversity of loads and other attendant economies and the well established movement toward general and extensive interconnection is still gathering headway. The relation of the railroad electrification problem to fuel conservation is well recognized and for years has been consistently expounded by able engineers.

These influences lead directly toward large scale development, at the source, of our natural energy reservoirs, the coal fields and the potential water powers. An essential feature of such development will be the transmission electrically of great blocks of power, over increasingly great distances, to strategic centers of distribution in or near present and future industrial districts. This trend of the power industry has long been recognized, and important steps toward its realization are a certain and not distant eventuality. Further elaboration of the subject is unnecessary to the purposes of this paper.

THE FIELD FOR 220-KV. POWER TRANSMISSION

Visualization of the demands of this evolution points to the need of trunk electric transmission service of a capacity and range of greater magnitude than thus far developed or required. Increasing distances and increasing quantities of power require an increasing voltage for economic transmission. The quantities and distances involved in the broad field outlined in the preceding paragraph pass beyond the economic range of existing transmission voltages. The practical working out of this next step in the transmission art is a problem now definitely facing the engineer and manufacturer.

Scarcely more than ten years ago an operating voltage of 100 kv. was remarkable; today 130 kv. may be considered standardized and 150 kv. is in sufficiently extensive use to have established its reliability.

Two hundred and twenty kv. appears a logical choice for the next step in the transmission voltage schedule. Why 220 kv., it may be asked? Because, from an appraisal of the general situation, a voltage of this order is considered adequate for the immediately pending needs of the industry and commensurate with expected growth in transmission service demands for a considerable period. Its suitability to a variety of conditions and the probable extent of its use would assure it a place in the schedule of transmission voltages which commercial needs are rapidly standardizing. Furthermore, such a voltage, while representing a step beyond present usage sufficient to afford a distinct economic advantage, does not reach so far into uninvestigated fields but that the problems of development and design can be approached with full confidence of early commercial solution.

The particular numerical value of 220,000 is in accord with the well established practice of standardization in multiples of 11,000. In some instances, it may be an incidental convenience that this voltage is the double of the extensively used 110 kv.

An illustration of the advantage for long transmission distances of 220 kv. over the highest present system voltage, 150 kv., is given in Figs. 1 and 2. This comparison is based upon a transmitted load of 500,000 kw. The same relative advantages will obtain for larger loads, and, above a certain minimum, for smaller loads.

The field of 220 kv. is not broad. Its economic application is primarily to large blocks of power and long transmission distances. It is in no sense a panacea for transmission problems generally. It presumably will infringe to some extent upon the present fields of the lower transmission voltages, but will by no means tend to supersede their use, in fact it will considerably enlarge the field of usefulness of such secondary transmission voltages as 66 kv. and 110 kv. It is not a universally suitable medium for extensive interconnection of power systems.

Power from steam-electric stations in the coal fields or from large hydroelectric stations would advantageously be transmitted over 220-kv. lines to terminal substations at important load centers or at the hubs of secondary transmission networks serving industrial areas. The introduction of transmitted power, in amounts limited only by the load demands, will constitute a strong stimulus to expansion of these networks.

Power equalization between load centers might frequently best be accomplished through extension of these secondary transmission lines. Interconnection at 220 kv. would be expected only where the equalizing duty reaches a large magnitude, where there is no existing secondary transmission system suitable to serve as a basis for inter-connecting lines, or where interconnecting 220-kv. lines might function also as a supplementary or important reserve link in a main 220-kv. trunk transmission system.

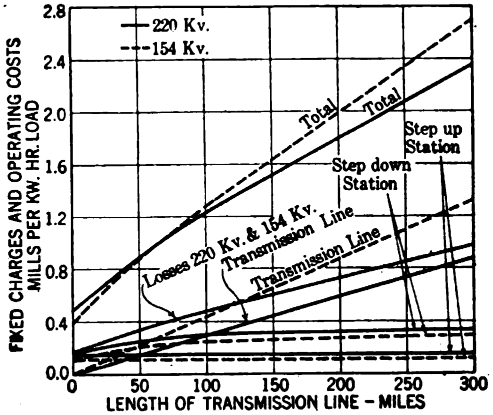


Fig. 1—Economic Comparison of 154-kv. and 220-kv. Transmission—Fixed Charges and Operating Costs—Seven Lines 154 kv. and Four Lines 220 kv.—500,000 kw. Delivered

Costs and losses include those of lines, step-up and step-down, substations and synchronous condensers.

Costs of line per mile, 154 kv. $20,000, 220 kv. $23,500—all costs based on early 1919 prices.

Size of conductor 92,900 cm. steel—716,000 cm. aluminum.

Losses based on 0.95 load factor and 0.85 power factor delivered load.

Cost of energy 5 mils per kilowatt-hour.

Fixed charges and operating expenses of transmission lines 13 per cent, substations 15 per cent.

Voltages high side of transformers, receiver end 150 kv. and 200 kv., sending end 170 kv. and 225 kv.

To a marked extent, and especially in the earlier stages of its introduction, power transmitted at 220 kv. will be high load-factor power. The initial investment in a 220-kv. system, including as essential elements the step-up and step-down stations, will be of such magnitude that there will be a strong inducement to utilize the investment as nearly continuously as practicable, thus reducing the unit transmission cost of energy supplied. The natural economic tendency in introducing power transmitted from distant energy sources will be to supply base load, leaving the peak loads to existing local generating stations. It is to be expected that high voltage transmission from energy sources, fundamentally economic as it is believed to be, will in general for years contribute only a part of the power supply of any district. The relegation of existing stations to partial operation or reserve service will be gradual, and, even when transmitted power becomes the main reliance, presumably it will usually prove more economical to maintain local stations for reserve and short peak load service than to provide necessarily expensive transmission capacity for such short periods of actual use.

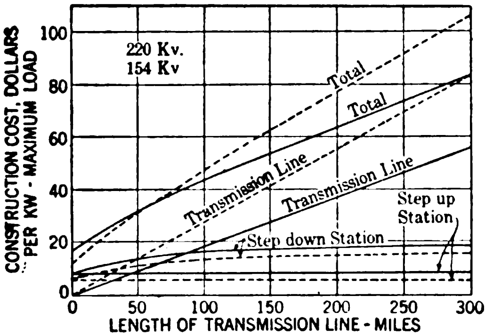


Fig. 2—Economic Comparison of 154-kv. and 220-kv. Transmission—Construction Cost—Seven Lines 154 kv. and Four Lines 220 kv.—500,000 kw. Delivered

Costs include those of lines, step-up and step-down substations and synchronous condensers.

Costs of line per mile 154 kv. $20,000, 220 kv. $23,500—all costs based on early 1919 prices.

Size of conductor 92,900 cm. steel—716,000 cm. aluminum.

Voltages high side of transformers, receiver end 150 kv. and 200 kv., sending end 170 kv. and 225 kv.

A characteristic of the field of 220-kv. transmission which exercises a determining influence upon designs and costs is that it is a field of high service standards. A 220-kv. system, with the generating stations for which it would be the outlet, would represent a tremendous amount of power. The economic importance of reliability and continuity of this power, in view of the great volume of industrial enterprises and public utilities which would be dependent upon it, is of so high an order that new standards of care in design and conservation in construction are imposed. The aim, and a not unrealizable aim, is to make high-voltage, large-capacity transmission for all practical purposes equal in dependability to local generation of power.

SCOPE OF PAPER

Based upon such a conception of the field of 220-kv. transmission, it is the aim of this paper to carry through an analysis of a typical transmission problem, sufficiently specific as to assumptions to afford a basis of designs, but not limited to any exact geographical location. Conditions underlying designs are analyzed, certain salient features of the design of lines and apparatus are discussed, proposed types of construction are considered and an effort is made to point out the problems of the designer and the manufacturer, particularly in those applications where there is apparent need of more thorough investigation and research before particularized conclusions can be drawn with confidence. It is not intended that the paper be in any sense exhaustive as to completeness of conclusions or solution of details of the problem, which for any specific case will involve extensive and thorough studies and investigations based upon specific load characteristics, geographical conditions and other basic considerations.

The studies have been guided by the desire that any recommendations should be capable of prompt commercial execution. In other words, it has been the aim to outline a type of construction built up essentially of established factory products in such way as to insure initially successful results. At the same time an attempt has been made to point out the short-comings which must be tolerated and the apparent opportunities for more efficient solutions.

It is the desire and hope that this tentative development of the problem in outline will afford a basis and incentive for full and constructive discussion by those interested in the advancement of the art of power transmission. It is hoped also that it may encourage designing engineers and manufacturers to undertake needed investigations into insufficiently explored fields as the foundation for developing designs for suitably improved apparatus and line materials. There would seem to be promising opportunities for distinct and beneficial departures from prevailing practises.

DESIGN FEATURES OF 220-KV. TRANSMISSION LINES

General Assumptions. Before considering the specific designs which are suggested for 220-kv. transmission lines, a brief statement will be made of the basic underlying assumptions as to loads to be transmitted, as to frequency and type of system to be adopted and as to climatic loadings and corona conditions to be assumed.

As to amount of load to be transmitted, it is assumed that even an initial 220-kv. system would be laid out on a basis of two or more main generating stations connected to load centers by a number of circuits. The load per 220-kv. circuit has been assumed to be from 100,000 kw. to 125,000 kw. A lower load per circuit than 100,000 kw. would entail a considerable sacrifice of the economy obtainable through use of 220 kv. No discussion is offered as to the maximum economic load per 220 kv. circuit, *i. e.*, as to the point above which additional circuits should be provided, since in any initial system the number of circuits would be determined from considerations rather of reliability insurance or load distribution than of maximum inherent economy. Where the studies involve a specific transmission distance, 250 miles has been assumed for purposes of illustration. The economic range of 220 kv. as to distance is very large.

The frequency of a 220-kv. trunk transmission system should be 60 cycles. For a general power distribution system furnishing lighting and power service in cities and industrial centers, the superiority of 60 cycles over 25 cycles has been well established, and for a transmission system delivering power to such a distribution system, the decision as to frequency unquestionably must follow the requirements of the load. In some districts, for which 220-kv. transmission may come up for consideration, it presumably will be found that both 60 cycles and 25 cycles are in use, possibly that 25 cycles in amount of load is still predominant. Even in these cases, however, the tendency in new development will be found away from 25 cycles, and it would be serious economic error to compromise so important an undertaking as a 220-kv. transmission system with a frequency approaching obsolescence.

High-capacity long-distance transmission will inevitably play a significant part in electrification of main line railroads. In instances where alternating current electrification is an important factor in a project, there may be greater seeming inducements in favor of 25 cycles, but even in such cases it is believed that consideration of the general and industrial portions of the load, of the probable tendency of future growth and of the trend toward wide-spread interconnection will lead to a decision for 60 cycles.

From the standpoint of line performance alone, use of the lower frequency would afford better conditions of voltage regulation, but with synchronous condensers, which must be regarded as an integral part of a modern high capacity transmission system, the problem of satisfactory regulation at the higher frequency is not serious. Incidental considerations, none of them relatively important, are greater cost of 25-cycle equipment, lower reactance of a 25-cycle system and hence, heavier circuit breaker duty, and lower corona loss for 25 cycles.

The step to 220 kv. will by no means be the ultimate development in power transmission. Eventually a demand may be expected for transmission capacities and distances beyond the economic range of this voltage, and the advance then to be evolved may conceivably abandon 60 cycles for some very low frequency, for direct current or for some other revolutionary change in the tran mission art. Such remote eventualities, however, do not affect the considerations governing the step to 220 kv.

Transformer connections, at all installations, should be grounded Y for the 220-kv. windings. The question of Y *vs.* delta connections has in the past evoked considerable discussion for each new undertaking, whatever the specific requirements of the system, and debate may arise in connection with projected 220-kv. transmission. Modern thought and experience shows a consistent tendency toward the use of grounded Y connections over the whole range of higher voltages. For a 220-kv. system, in addition to a distinct gain in dependability of operation, the requirements for line and equipment insulation, with their attendant effect upon the size and cost of equipment, particularly transformers, gives the grounded Y arrangement a marked advantage.

The simultaneous conditions of maximum climatic conductor loading used as a basis for line design have been assumed as follows:

a. Wind pressure of 8 lb. per sq. ft. of projected area, corresponding to an indicated wind velocity of 72 mi. per hr.;

b. Ice of 1½ inches radial thickness on all wires;

c. Temperature of 0 deg. fahr.

For checking clearances of conductors a maximum temperature of 120 deg. fahr. has been assumed.

These loadings are, of course, far in excess of those used as a basis for ordinary transmission line design. It is not believed that there is any reasonable likelihood of the line being subjected to such a simultaneous combination of conditions. From the standpoint of vertical tower loads; there is a real possibility of occasional ice loadings as heavy as or even heavier than assumed, and accordingly a reasonable margin of excess vertical strength is called for. Justification for these apparently extreme loading assumptions is found in the high service standards which, as noted, must in general apply in 220-kv. service. In view of the economic importance of continuity of service, it is considered that this basis is not unreasonable for a region where severe climatic conditions obtain, and in particular where heavy sleet is to be expected. Where climatic conditions are more mild, a lighter loading basis should naturally be assumed. In the planning of any particular project, this question of assumptions as to line loading, and the underlying economic conditions, should receive most careful consideration.

Corona formation and corona loss enter as a significant factor in the design of transmission lines at this high voltage. The conditions assumed for this study are:

a. Average elevation, 1000 ft. (normal barometer 28.9 in);

b. "Storm factor", or percentage of time during which conductors would be subject to increased corona losses due to rain, snow, sleet or fog, 12.5 per cent;

c. Conditions during "storm" periods, 28.4 in. barometer, average temperature 55 deg. fahr.

Corona conditions likewise will require special study for each particular installation, particularly the matter of "storm factor." The ordinary source of data will be Weather Bureau records. The published reports, however, while complete as to amount of precipitation and number of days of which precipitation occurs, do not give in summarized form the actual duration of storm conditions. A reasonably correct value of the factor for any district may be obtained from study, extending over a considerable period, of the original records of individual storms at several stations in the district. The dividing line between "storm" and "fair" conditions is, of course, not clearly defined, and hence preciseness of results is difficult to attain.

Conductor Materials and Types. Apparently the choice of conductor materials and types for 220 kv. service is limited, at least from the standpoint of immediate availability, to three alternatives,

1. Aluminum with steel core.
2. Copper with steel core.
3. All copper.

Aluminum without steel core does not possess sufficient mechanical strength for use on the span lengths in current use for high-voltage transmission. From the standpoint of mechanical strength, copper may be used either with or without steel core. A copper cable with a core of some other type than steel strand is a possibility; hemp cores have been used, but experience, while inconclusive, appears to indicate that there may be injurious chemical action; a semi-hollow copper cable with internal spacers of wood or metal has been suggested, but its feasibility has not been demonstrated and there seem to be no real benefits. Such a dead weight "filler" decreases the effective strength of the cable.

As to the satisfactory performance of steel cored cables, there appears to be but one point open to question; *i. e.*, possible electrolytic action between the galvanizing coat of the steel and the main conductors. Composite aluminum cables have been coming into increasing use during recent years, and from the experience gained, there is growing assurance of freedom from electrolytic action which would materially impair the durability of the cable. Aluminum and zinc are not far separated in the electro-chemical series, and aluminum is electro-negative to the zinc, so that there is less reason for anticipating trouble. There has been less experience with copper cable with galvanized steel core, but theoretically the conditions are somewhat less favorable, since copper is farther separated from and electro-positive with respect to zinc. It may be noted, however, that no injurious action has been observed in the extensive use of galvanized fittings with copper cable. Further experience with such composite copper cables is awaited with interest. In case injurious electrolytic action is established with galvanized cores, there appear to be a number of possible remedies, such as the use of copper plated steel cores. A sufficiently heavy copper plating would, however, be more expensive than galvanizing.

In general, for equal conductivity, the relative physical advantages of the three types of conductors may be summarized as follows. Certain features noted will later be discussed in more detail.

Aluminum-steel vs. copper-steel

1. Less corona loss, due to larger diameter
2. Skin effect presumably approximately equal
3. Greater area exposed to wind loading, hence, greater transverse tower strength and greater clearances required
4. Less tensile strength, hence more limitation upon height and spacing of towers
5. Less weight (unimportant)

All-copper vs. composite cable

1. More corona, greater than either of above
2. All material effective as a conductor
3. Skin effect more serious in larger sizes, owing to high priced material in the core
4. Less area exposed to wind loading
5. Less total·tensile strength than either of above
6. Less weight than copper-steel
7. Homogenity of material, hence certain advantages in construction, more positive assurance of durability and higher scrap value

It will be seen that aluminum-steel, due to corona limitations, has a greater relative advantage for smaller line loads, which economically require smaller sizes of cable than for larger line loads.

For any particular case and any given magnitude and character of load to be transmitted, the choice of conductor type will depend upon a complex economic balance between the cost of materials involved, the losses due to resistance, corona, and skin effect, and the mechanical characteristics of the cables. Different loads may call for different types.

For the purpose of developing tower designs, a cable of 716,000 cir. mils of aluminum and 93,000 cir. mils of steel has been used in the studies which follow, the considerations upon which this selection was made will be discussed later.

Electrical Characteristics of Conductors. At such a high voltage as 220 kv., one of the primary considerations in selecting size and type of conductor is corona formation and corona loss in its relation to conductor diameter. The subject has been extensively treated by Peek and others before the Institute and the methods of calculation outlined by these authorities have been employed in the studies which follow. In these methods of analysis, it is necessary to assign values to the principal factors affecting corona. The physical and climatic conditions assumed have been stated earlier. The conductor arrangement has been taken as a flat horizontal configuration

TABLE I

CORONA LOSS DATA ON CONDUCTORS FOR 220-KV. CIRCUITS 20-FT. HORIZONTAL SPACING
(See Fig. 3)

	Aluminum-Steel				Copper	Copper-Steel			
Conductor Designation (See Table 2)	A	B	C	D	E	F	G	H	K
Dia. of cable—Ins.	0.952	1.036	1.092	1.196	0.814	0.857	0.904	0.946	1.004
Fair Weather Disruptive Critical kv. (e_0)									
Center wire	129	139	146	157	114	118	124	129	135
Outer wires	142	154	161	174	126	130	137	142	150
Storm Disruptive Critical kv. (e_0)									
Center wire	103	111	117	126	91	94	100	103	108
Outer wires	114	123	129	139	100	104	109	114	120
Total kw. Loss—3 Wires—250 Mi. (100,000-*kw. Circuit*) *Storm Factor* 12.5 *per cent*									
60 per cent load factor	464	162	66	16	1986	1253	758	493	254
75 per cent load factor	425	141	57	12	1835	1152	694	452	227
90 per cent load factor	378	119	47	8	1664	1032	620	404	195

with conductors separated 20 ft. Proper allowance has been made for the unbalanced disruptive critical voltages due to this horizontal configuration. The conductor irregularity factor, taking into account the effect of weathering of the conductor with age and the irregular surface resulting from stranding, has been assumed as 0.87.

In Table I are shown, for a number of conductor sizes, the fair weather and storm disruptive critical voltages and the total corona loss for 250 miles of circuit. Corona losses for various load factors are shown graphically in Fig. 3. In determining the values of line voltage to be used in corona calculations, effective r. m. s. values of load were obtained from hypothetical daily load curves prepared for various load factors, and the mean voltages corresponding were determined from typical line regulation curves (Figs. 4, 5 and 6). It is believed that this method of analysis affords a reasonably and sufficiently accurate estimate of corona losses.

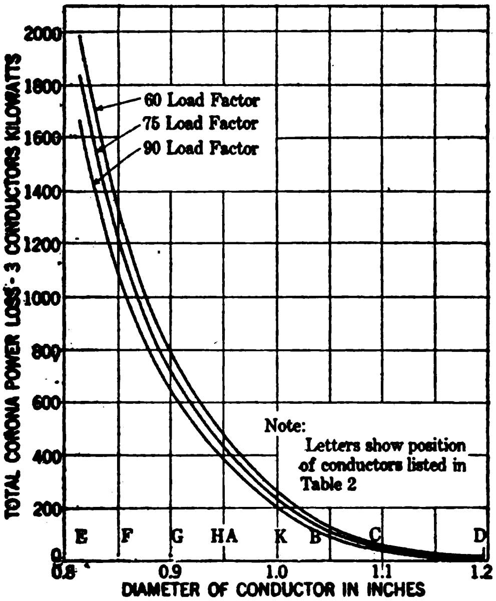
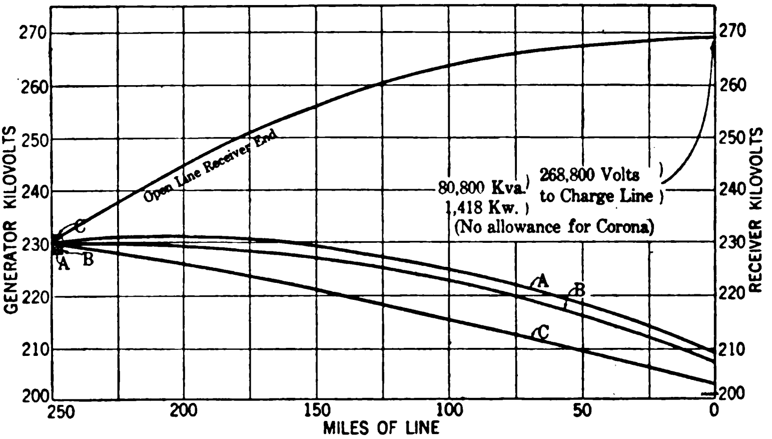


FIG. 3—220-KV. CORONA POWER LOSS FOR 20-MILE CIRCUIT (SEE TABLE I FOR EXPLANATORY DATA)
GENERATING VOLTAGE HELD CONSTANT AT 230 KV.

The electrical characteristics of composite cables, other than as regards corona, are somewhat more complicated of analysis than for a cable of homogeneous material, particularly as to the effects of the steel core on the internal inductance and effective resistance of the conductor. In the preparation of these studies, access has been had to data from certain experiments recently conducted in regard to these effects. It is understood that the investigators who have been carrying out these experiments anticipate presenting their findings in some detail to the engineering profession at an early date. It may be stated that this investigation indicates that in the practical



RESULTS

Curve	Rec'r kw.	Cond'r kv-a.	High voltage				Equiv. low voltage gen.		Losses (excl. corona loss)	
			Receiver		Generator					
			kv.	% p. f.	kv.	% p. f.	kv.	% p. f.	kw.	%
				250 mile line						
A	0	*49,800	209.0	* 0.18	230.0	† 4.61	227.9	† 4.69	2,646	..
B	50,000	† 7,500	207.2	*78.00	230.0	† 96.15	228.1	†97.28	2,780	5.6
C	100,000	†81,000	203.0	*98.72	230.0	*100.0	231.3	*99.67	11,927	11.9

NOTE: *Indicates lagging quantities.
†Indicates leading quantities.

FIG. 4—220-KV. TRANSMISSION LINE CHARACTERISTICS—RELATIONS BETWEEN KW., KV., P. F., AND CONDENSER KV-A.—CONDUCTOR—716,000 CM. ALUMINUM—92,900 CM. STEEL

CALCULATION ASSUMPTIONS

Steel core aluminum conductor—716,000 c. m. aluminum and 92,900 c. m. steel—20 ft. horizontal spacing

Constant receiver volts—200,000 (low side receiver transformer, includes transformer drop).

Constant generated volts—230,000 (high side generating transformer)

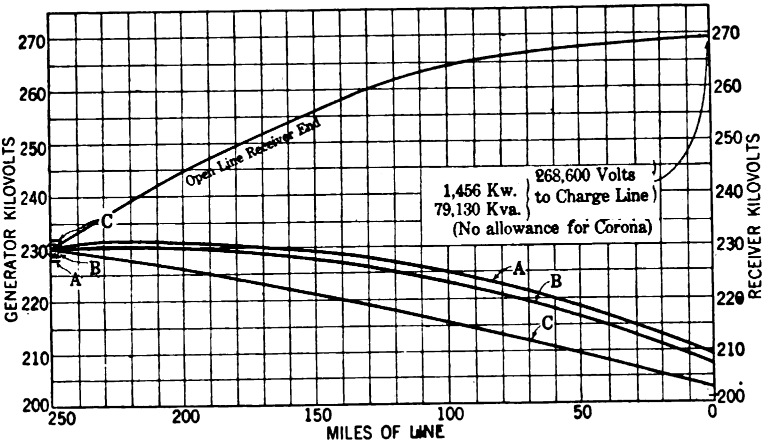
Loads—delivered at 75 per cent power factor

Transformer bank of 50,000 kw. capacity with—resistance 0.5 per cent, reactance 12.0 per cent

Two banks of transformers in parallel at each end of line.

Losses include those of line, transformers and synchronous condensers application of inductance and resistance formulas and calculations to transmission line studies, the effect of the steel core may be neglected.

Skin effect assumes appreciable proportions for the large



RESULTS

Curve	Rec'r kw.	Cond'r Kv-a.	High voltage				Equiv. low voltage gen.		Losses (excl. corona loss)	
			Receiver		Generator					
			kv.	% p. f.	kv.	% p. f.	kv.	% p. f.	kw.	%
				250 mile line						
A	0	*49,000	209.0	* 0.18	230	† 5.48	227.9	† 5.56	2,704	..
B	50,000	† 7,600	207.2	*78.24	230	†96.89	228.6	†97.70	2,691	5.4
C	100,000	†81,600	202.9	*98.80	230	*99.97	231.7	*99.51	11,843	11.8

NOTE: *Indicates lagging quantities.
†Indicates leading quantities.

FIG. 5—220-KV. TRANSMISSION LINE CHARACTERISTICS—RELATION BETWEEN KW., KV., P. F. AND CONDENSER KV-A.—CONDUCTOR—450,000 CM. COPPER—308,200 STEEL

CALCULATION ASSUMPTIONS

Steel core copper conductor—450,000 c. m. copper and 308,200 c. m. steel—20 ft. horizontal spacing.

Constant receiver volts—200,000 (Low side receiver transformer—includes transformer drop)

Constant generated volts—230,000 (high side generating transformer)

Loads—delivered at 75 per cent power factor.

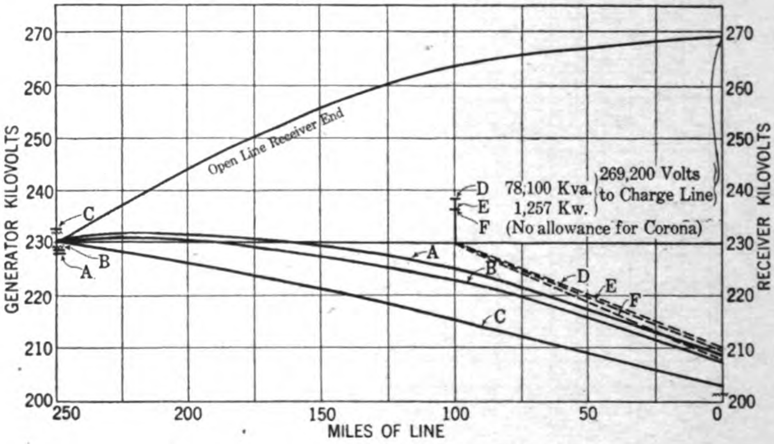
Transformer bank of 50,000 kw. capacity with—resistance 0.5 per cent—reactance 12.0 per cent

Two banks of transformers in parallel at each end of line.

Losses include those of line, transformers and synchronous condenser

sizes of conductor called for by 220-kv. transmission, particularly in case of the larger sizes of all-copper cable. The calculation of skin effect in composite cables is somewhat more complicated and burdensome than in the case of a homogeneous conductor.

The operating characteristics of a 220-kv., 250-mile line are illustrated by Figs. 4, 5, and 6, which show for an aluminum-steel, a copper-steel and an all-copper conductor the relations between power transmitted, generator, receiver and line voltages, power factor, condenser load and resistance losses.



RESULTS

Curve	Rec'r kw.	Cond'r kv-a.	High voltage Receiver		High voltage Generator		Equiv. low Voltage gen.		Losses (excl. corona loss)	
			kv.	% p. f.	kv.	% p. f.	kv.	% p. f.	kw.	%
			250 mile line (solid line)							
A	0	*49,000	209.0	* 0.17	230	† 5.2	228.0	† 5.3	2,607	..
B	50,000	† 7,000	207.5	*77.8	230	†97.3	228.6	†98.1	2,168	4.3
C	100,000	†80,000	203.0	*98.5	230	*99.9	232.5	*99.3	10,562	10.6
			100 mile line (dotted line)							
D	0	*57,500	210.3	* 0.20	230	* 2.0	236.3	* 2.09	3,158	..
E	50,000	* 4,900	209.4	*68.5	230	*81.1	236.2	†79.1	1,478	3.0
F	100,000	†54,000	208.0	*91.5	230	*92.8	238.2	*90.0	6,242	6.2

NOTE *Indicates lagging quantities
†Indicates leading quantities.

FIG. 6—220-KV. TRANSMISSION LINE CHARACTERISTICS—RELATION BETWEEN KW., KV., P. F. AND CONDENSER KV-A.—CONDUCTOR—500,000 CM. COPPER

CALCULATION ASSUMPTIONS

500,000 cm. copper (no steel core—20 ft. horizontal spacing.
Constant receiver volts 200,000 (low side receiver transformer—includes transformer drop)
Constant generated volts 230,000 (high side generating transformer)
Loads—delivered at 75 per cent power factor.
Transformer bank 50,000 kw. with resistance 0.5 per cent, reactance 12.0 per cent
Two banks of transformers in parallel on each end of line.
Losses include those of line, transformers and synchronous condenser

Necessary explanatory details are shown in tabulations accompanying the curves. These studies show that effective voltage regulation of such long distance, high capacity lines may be obtained by means of large, but not impracticable, synchronous condenser installations.

A study of the relative economy of various sizes and types of conductors is shown in Fig. 7, with accompanying explanatory data in Table II. This study shows, for a load of 100,000 kw. per circuit delivered at 0.75 power factor and at load factors of 60 per cent, 75 per cent and 90 per cent, that the combined annual costs of such items of the transmission system as would be materially affected by the size and type of the conductor, *i. e.*, interest, taxes and amortization charges on cost of conductor, annual value of lost power on the line due to resistance and corona and of power absorbed by transformers and condensers. The curve falling lowest on the scale, at any number of years which may be assumed as the life of the line, represents the most economical of the conductors considered.

This curve is presented merely as an example of the general method followed in studying conductor economy. It does not represent the degree of refinement which would be warranted in making final determination of the economical conductor for an actual 220-kv. installation. Other items for which allowance should be made in such a study are the effect of conductor size and type upon cost of line structures and insulators, and the possible scrap value of the conductor. Amortization should preferably be calculated by the annuity or "sinking fund" method rather than by the simpler straight line method. It should be noted, however, that these additional refinements tend in some respects to offset one another, a feature which gives added justification for their omission from a preliminary study. Obviously, in any case great refinement in the technical assumptions is not called for until reasonably close values can be assigned to cost of conductor materials, for which the market will presumably be unstable for some time to come, to the equivalent costs of the power losses, and to the percentages to be employed for return on investment, taxes, etc.

For the purpose of developing the line designs which will be presented later, a cable was chosen consisting of 716,000 cir. mils of aluminum (54 strands of 0.1151-inch diameter) and 93,000 cir. mils of steel (7 strands of 0.1151-inch diameter). Particular attention, however, is called to the fact that these designs were started and this conductor chosen as a basis of study about a year ago, when prices were much higher than at present, and further that the choice was made upon the basis of a lower load factor than, in the light of further study, seems reasonable to assume as likely to obtain on the usual 220-kv.

transmission system. It is fully recognized that at present price levels and for a high load factor, the economical size of conductor would be larger than this, and that possibly the economic advantage would fall to a different type.

Mechanical Characteristics of Aluminum-Steel Conductor. The large and heavy cables required for 220-kv. transmission, and the heavy conductor loadings which the importance of 220-kv. service requires as a design basis, together with the unusual general precautions which must be taken to assure reliability, call for a new order of refinement in the mechanical features of line design. Careful study with a high degree of imaginative foresight is required to provide against unsafe loads being imposed upon insulators and towers or clearances being dangerously reduced as a result of unusual or unexpected con-

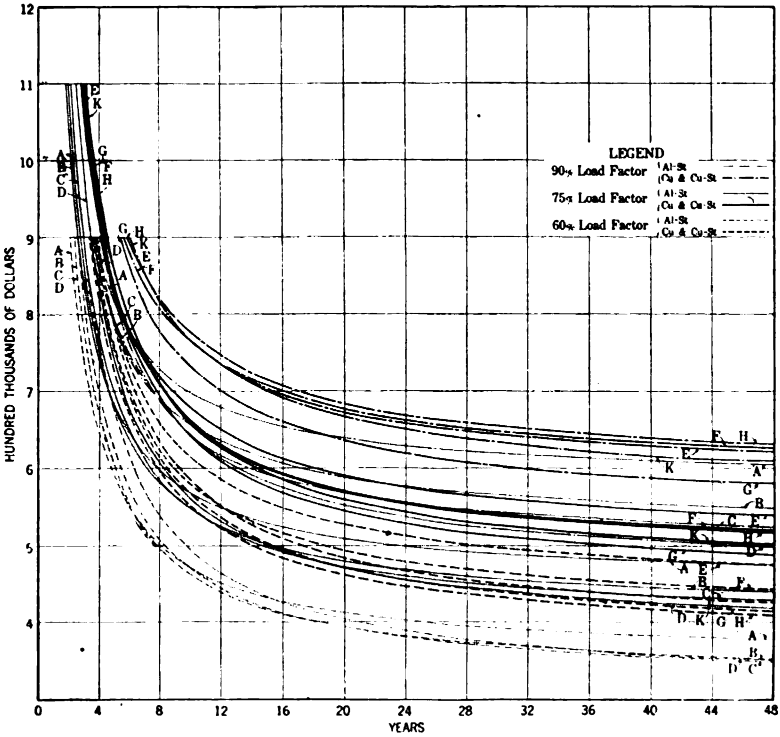


FIG. 7—ECONOMIC COMPARISON OF 200 KV. TRANSMISSION CONDUCTORS—ANNAUL COST CURVES—250 MILE, 100,000 KW. SINGLE CIRCUIT LINE (SEE TABLE II FOR EXPLANATORY DATA)

tingencies, and against possible unpreventable failures becoming cumulative and occasioning extensive damage.

The mechanical characteristics of steel-core aluminum cables are complicated, and calculation of stresses and sags under varying loading and topographical conditions presents an involved and difficult problem. This is due to the fact that the co-efficients of expansion and moduli of elasticity are different for the two metals and consequently are not accurately determinable for the composite cables. The cable manufacturers, however, have investigated these characteristics and have developed practical, though laborious, methods of calculation of conductor stresses and sags. These methods have been followed and are considered in the main to give results of an accuracy satisfactory for design purposes.

TABLE II

DATA RELATING TO ECONOMIC COMPARISON OF 220 KV. TRANSMISSION CONDUCTORS

(See Fig. 7)

ANNUAL COST CURVES FOR 9 DIFFERENT CABLES AT 3 LOAD FACTORS

1. Annual cost curves are plotted, dollars as ordinates, years as abscissas, and show the annual cost for any period up to 48 years. This is explained as follows:

Annual Cost Includes
1. Depreciation expressed as first cost divided by number of years chosen.
2. Yearly interest and taxes taken as 8 per cent of first cost.
3. Annual value of Lost Power taken as 5 mills per kw-hr.

First Cost includes only cost of finished Aluminum-Steel Cable at 44.9c. per lb. for aluminum and 12.2c. per lb., for steel f. o. b. factory. First Cost of finished copper or copper-steel cable @ 27.7c. per lb. for copper and 12.2c. per lb. for steel f. o. b. factory. All other items of construction costs have been eliminated as not materially affecting the relative positions of the curves.

Lost Power includes line $I^2 R$, transformer I^2R, condenser loss and Corona loss.

2. Cable Data.

Curve designation (See Fig. 7)	Kind of cable	First Cost	Alum. or copper	Steel	Total of cable	Alum. or copper	Steel	Diam. of cable
A	Al.-St.	$1,175,700	605,000	78,000	683,500	54	7	0.952
B	Al.-St.	1,362,800	716,000	92,900	808,900	54	7	1.036
C	Al.-St.	1,513,500	795,000	103,100	898,100	54	7	1.092
D	Al.-St.	1,814,000	954,000	123,700	1,077,700	54	7	1.196
E	Copper	1,764,800	500,000	....	500,000	37	..	0.814
F	Cu.-St.	1,733,300	450,000	105,000	555,000	30	7	0.857
G	Cu.-St.	1,924,400	500,000	116,600	616,600	30	7	0.904
H	Cu.-St.	1,790,200	400,000	274,000	674,000	54	37	0.946
K	Cu.-St.	2,011,700	450,000	308,200	758,200	54	37	1.004

The basic data for calculations have been taken as:

	Aluminum	Steel
Elastic Limit (lb. per sq. in.)...........	14,000	130,000
Modulous of elasticity (lb. per sq. in.) ..	9×10^6	30×10^6
Co-efficient of expansion (per degree fahr).............................	12.8×10^{-6}	6.4×10^{-6}

Elastic limit of composite cable 17,300 lb.
(716,000 cir. mils aluminum, 93,000 cir. mils steel)

Within any limits thus far investigated, it appears economical under the design loading, to utilize the full strength of the conductor up to its elastic limit, *i. e.*, to keep sags to a minimum, thus enabling use of shorter towers or longer spans at the expense of stronger supporting structures at angles and dead-end points. With a new aluminum-steel cable, when the loading has been reached which will stress the steel core to its elastic limit, the aluminum will have passed its elastic limit and in consequence have been permanently stretched. The full working strength of the cable, 17,300 lb., will then have been developed, and it may then be said to have reached its final stretched condition, *i. e.*, to have received its "permanent set". As the heavy design loading is removed, the action of the aluminum strands will be to loosen infinitesimally on the steel core and to take no stress. In any subsequent applications of the design loading, the core will again be stressed to the elastic limit of the steel, and the aluminum will coincidentally reach its own elastic limit stress. At lighter loadings the aluminum will be a dead load upon the steel core, which will carry all of the stress.

This introduces an interesting feature in that the characteristics of the composite cable when *new* are distinctly different from its characteristics after it has received its "permanent set," and, for loadings less than the design loading, will follow different tension-sag curves. This relation is shown graphically in Fig. 8.

The problem of predetermining stringing sags for a suspension insulator line, in which there will be considerable differences in lengths of adjoining spans and in elevations of the ends of individual spans, involves considerations of unbalanced tower loads, abnormal insulator loads and reduced tower and ground clearances under varying conditions of conductor loading. It is necessary, initially, to assume a somewhat different mental attitude toward the problem of conductor stringing than that which largely has been customary. For the conditions of 220-kv. design, with heavy design loadings and large conductors under heavy tension, the problem assumes greater importance than in transmission line practise heretofore. In usual practise on suspension insulator lines, the conductor is strung to a certain predetermined tension, derived from tension-sag curves on the basis of the *average span* length between dead-end points, and the suspension insulators are then tied in in a vertical position. It is assumed that when the design loadings occur the conductor tensions and attendant loads upon insulators and towers will continue to maintain the condition of proper balance of stresses within reasonably close limits. Probably, with most present lines, the resulting unbalanced effects under design loading will not be serious. Under the assumed 220-kv. design conditions, preliminary

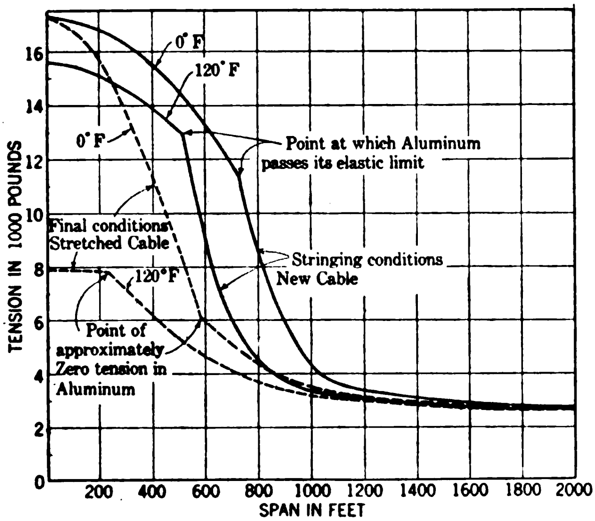


FIG. 8—TENSION—TEMPERATURE CURVES—DEAD ENDED SPANS—STRINGING AND FINAL CONDITIONS—CONDUCTOR—ALUMINUM 716,000 CM.—STEEL 92,900 CM.

Steel reinforced aluminum cable—716,000 c. m. aluminum—92,900 c. m. steel—elastic limit of cable and maximum allowable stress—17,300 lb. with 1½ inch ice and 8 lb. wind at 0 deg. fahr.

Solid line curves represent stringing tensions of new cable, without load, before first application of maximum loading.

Dotted line curves represent final tensions of stretched cable, without load, after application of maximum loading has given a permanent set to the aluminum.

study has shown that such a method of stringing will result, under the extremely heavy design loading, in great longitudinal deflections of suspension insulators intended to operate purely as suspension units, and will consequently impose unsafe tensions upon these insulators, with attendant unbalancing of tower loads and possibly dangerous reduction in tower clearances, in addition to over-stressing and stretching the conductor itself.

The theoretically proper point of view is that, under design loading conditions, the conductor should be uniformly stressed to its elastic limit and insulators should be hanging normally. Assuming the line to be in this condition under maximum load, the inverse of the condition just described will occur as the load is removed and the conductor contracts in length, that is, the suspension insulators will assume certain definite deflections at towers between spans of different lengths and at adjacent towers at different elevations, resulting, of course, in a non-uniform tension in the conductor itself. It is this unbalanced condition without load which careful design should aim to produce in initial stringing. This method of stringing might, however, in some cases result in excessive insulator deflections and tensions under the non-loaded condition of the conductor, and some compromise between the two methods may be necessary to safeguard the clearances of the unloaded conductors.

A method of predetermining for stringing conditions the proper conductor tensions or sags in individual spans and the proper insulator deflections is accordingly a desirable refinement. Some approximate treatment of the subject, at least, will probably be necessary. It should be noted that the 220-kv. designs suggested in this paper contemplate the use of very long suspension insulator strings, and that this length of string tends to lessen the amount of abnormal insulator and tower stresses and reduction of tower clearances which may be set up. If, as is hoped, improvement in insulator design should enable the adoption of a shorter insulator, an accurate method of conductor stringing will become correspondingly more important.

A purely mathematical treatment of the problem appears complex in the extreme, although approximate methods of analysis seem to be feasible. The working out of such approximate methods offers an interesting and valuable subject for research. An exceedingly instructive experimental investigation could be made along these lines, either by means of a series of spans of a full-sized line capable of being artificially loaded, or by means of a miniature properly proportioned model. One troublesome feature of such an experimental determination of these phenomena would seem to be that of readily obtaining and controlling the necessary temperature range, or of compensating or correcting for temperature variation by some indirect means. Such an investigation would fulfill a most valuable function in supplying empirical constants to be used as a basis for mathematical treatment and in verifying the results of approximate methods of analysis.

The problem of actual stringing is further complicated by the use of a composite cable, owing to the shifting of tensions between the aluminum and the steel, and especially to the radically different characteristics of the cable before and after it has been stretched to receive its "permanent set", as previously described and as illustrated by Fig. 8. This difference in characteristics leads to the possibility of two different methods of stringing a composite cable, *i. e.*, it may be strung as received from the factory, or it may be stressed, prior to sagging and tying in, to its full strength, 17,300 lb., thus giving it nearly all of its "permanent set" (it would receive all of its "permanent set" if the stretching were done at 0 deg. fahr. In the latter case a series of tension-sag curves based upon the "permanent set" condition of the cable would be used for stringing. In the case of stringing the new unstretched cable, it would be necessary to develop a special series of tension-sag curves, while the "permanent" tension-sag curves would be used in locating towers and checking clearances.

For a new cable, in the absence of special data, the division of stress between the aluminum and the steel is indeterminate. Such special data may, however, be obtained, presumably by experiment. It probably will be found that the conditions of the cable as it comes from the factory is sufficiently uniform to enable such special stringing curves to be used consistently. The application of methods predetermining insulator deflections, as discussed above, would involve even further complication if these special unstretched tension-sag curves were to be used for stringing.

From the operating standpoint, however, it would seem preferable to string the cable without preliminary stretching.

The design loading, with the large margin of safety which it is assumed to contain, will probably rarely be reached or approximated on the greater portion of the line. The smaller initial sags would then in practise, for the greater part, never be increased to the "permanent" sags by natural causes. Hence, there would be obtained the advantage of smaller normal operating sags, with the unstretched aluminum acting as a reserve to increase them suitably when, or if, the design loading should occur.

Possibly a combination of the two methods might be worked out, whereby the cable would be stressed before tying in to some definite tension sufficient to insure giving the aluminum part of its "permanent" set. It would then be sagged in by unloaded tension-sag curves based upon the definite relation between stresses in the aluminum and the steel as established by this preliminary application of tension.

The practical importance of the theoretical considerations involved in stringing irregular spans supported by suspension insulators, and the extent to which refinements may and should be carried will in the last analysis be governed by consideration of the practical limits of field application, taking into account the many variable physical and personal factors. The intent is to point merely to the interesting and apparently effective possibilities of theoretical and experimental research, pending further analysis and study. No field stringing curves embodying the refinements suggested have yet been developed, even in approximate form. For purposes of clearance determinations, of tower design and of study of tower economics, the use of "average span" tensions and sags probably embodies sufficient accuracy, and has tentatively been used.

Adequate splices for aluminum-steel cables no longer are considered to present a problem. Satisfactory types have been developed and are in successful use on existing lines. In making these splices, the aluminum is cut back from the ends of the steel core, the core is then spliced by means of a soft steel sleeve, twisted on by means of special wrenches, and the sleeve and a considerable length of the aluminum strand at each end are then covered by a heavy aluminum sleeve which is solidly compressed on the conductors between the dies of a portable oil operated jack. Such splices are reported to develop the full strength of the cable, the splice itself having considerable excess strength.

Overhead Ground Wires. The line designs presented provide for two overhead ground cables of 5/8-inch diameter high-strength steel, 16,000 lb. elastic limit for the cable. The justification for the use of ground wires in 220-kv. transmission is debatable, but no well-formed conclusions seem possible except as a result of practical comparative experience. Their use on present high-voltage steel tower lines is nearly universal, remarkably so in view of the meagre and inconclusive character of the data as to the benefits derived. At 220 kv., with the high insulation provided and in view of the diminishing importance which, with increasing line voltage, it is believed can be attached to induced lighting disturbances, it is wholly conceivable that the protection afforded may be found to be of disproportionately small value. The cost of using ground wires is undoubtedly a large item, particularly in view of the extremely heavy design loadings assumed and the consequent tower stresses which they occasion.

In view, however, of the great importance of 220-kv. service, it has been deemed conservative, until further experience is obtainable, to make provision for the use of ground wires. The plan of installation would be to omit ground wires from a considerable portion of one line, in districts where lightning conditions were severe, while ground wires would be used on a parallel line. Comparative performance data would be a guide to subsequent procedure.

Types of Insulators Available. There is no type of insulator as yet developed which has thus far demonstrated its ability to give adequate, or even reasonably satisfactory results on high-voltage lines. This condition, however, applies nearly as much to the high voltages in current use, 110 kv. to 150 kv., as it does to 220 kv. It does not in any way affect the feasibility of 220-kv. transmission. It is confidently believed that 220-kv. line insulation can, with existing types of insulators, be made as safe and dependable as can the line insulation of present installations. In fact, where foresight in design and careful maintenance are employed, the present unsatisfactory insulator situation makes its effects evident far less in impairment of service reliability than in the high first cost, direct and indirect, of precautions against insulator failure and in high maintenance expense and operating inconvenience. The economic value of 220-kv. service is so high that greater expense and attention than at lower voltages are warranted in measures to guard service.

The probable advent in the near future of such voltages as 220 kv. should serve, nevertheless, to emphasize the economic necessity of developing line insulators to a point consistent with the other elements of the electric power generation and transmission situation. The baneful effects of the insulator situation are evident not merely in the expense and trouble occasioned, but in a certain degree of popular suspicion, in essentials unwarranted, of the general idea of high-voltage transmission.

It is believed, as has just been noted, that practicable 220-kv. insulators can be obtained from present established types. There are commercially available three such types, all based upon the principle of a series string of disks, in practise of about 10-inch diameter, *i. e.*, the standard cemented cap and pin type, the Hewlett type and the newer Jeffrey-Dewitt type. Numerous other designs for high-voltage insulators have been suggested, some of the series unit type and some in one piece. Certain of these designs appear to offer real promise, but none of them have been developed to the stage of commercial production, or even to a point where their service performance can be predicted.

The following studies and 220-kv. line designs have been based upon the standard 10-inch cemented cap and pin type units. This implies no disparagement of the other types mentioned; in fact, these appear in some respects to offer significant advantages. The standard type has been taken as a basis of study because it has been used by far the most extensively and for long periods, and, therefore, more data are available in regard to its characteristics. Any general designs of towers and fittings developed for these units could equally well be used for the other types. The studies which follow, in conjunction with the general record of experience and investigation, indicate that there are certain characteristics, largely inherent, of these standard disk insulators which render them far from ideal for service at extra high voltage with heavy conductors. In certain respects this would be true of any insulator built up of a large number of disks. It is hoped that manufacturers will soon be able to develop an insulator, which will be more suitable for extra high-voltage use and will offer assurance of greater strength and permanence, both electrically and mechanically.

Electrical Characteristics of Disk Insulators. The designs suggested make provision for a string of 15 standard units for regular suspension service on a 220-kv. grounded neutral line. This relatively large number of units affords a considerable margin for deterioration and, with proper care in maintenance, should assure a degree of reliability in service commensurate with the economic importance of 220-kv. service.

It should be noted that a string of 15 standard units, with the necessary connecting pieces and fittings, will be nearly nine feet long. Such a length of insulator obviously involves great expense in obtaining the necessary tower clearances and heights, and it is also the determining feature in fixing conductor separation. This serves again to call attention to the need of more efficient and suitable insulators. An improvement in insulator design which would justify shortening the string, in addition to improving the electrical characteristics of the insulator itself, would enable material saving in tower costs. A wholly new insulator, having no greater length than necessary to insure requisite air clearances from conductor to support, say four or five feet, would enable a correspondingly greater and a very significant saving in tower costs. Such an insulator at moderate price might readily open the door to a variety of new types and arrangements of supporting structures.

The primary electrical characteristics are those of arc-over and puncture. It is essential to reliable service that units be employed with the largest obtainable ratio of puncture voltage to arc-over voltage. The particular importance of this high ratio for 220 kv. will be evident in the light of certain data which will be presented later in regard to concentrations of electrical stress upon individual units of the string.

The 60-cycle arc-over characteristics of long strings of standard disk insulators are shown in Fig. 9, which gives curves of arc-over voltage for wet and dry conditions. These curves are based upon published test data for shorter strings, extended mainly on a theoretical basis with the assistance of such fragmentary test data as have been available.* It is pertinent, and of great interest, to note that the dry arc-over curve flattens out as the number of units in the string increases, approaching a condition where increasing the number of disks adds practically nothing to the dry arc-over voltage, while on the other hand the wet arc-over curve follows nearly a straight line characteristic and for long strings reaches higher values than the dry arc-over curve. These characteristics, as is well understood, are due in the case of dry arc-over, to the action of the charging current on the system of distributed series and shunt capacities which the insulator string constitutes, the resultant effect being a concentration of potential on certain units of the string. In the case of wet arc-over, the effect of the charging current is lost in the greater effect of the large leakage current.

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*Peek, A. I. E. E. PROCEEDINGS, 1912—"Electrical Characteristics of the Suspension Insulator."

The dry arc-over characteristic thus appears to constitute the controlling feature of insulator design, in so far at least as 60-cycle characteristics are determining. The fact that an insulator has a higher arc-over value under rain conditions is of no advantage, since this condition obtains for but a small fraction of the time, and in particular since heavy lightning discharges, with possibility of resultant normal frequency surges on the line, are more likely to occur just before a rain storm than during it.

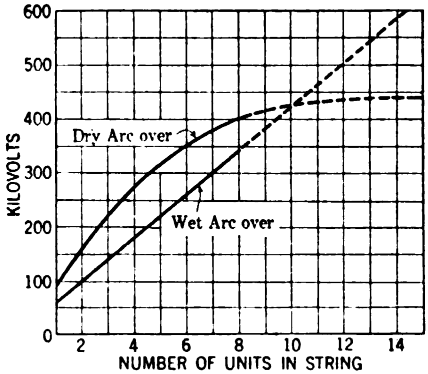

FIG. 9—TYPICAL 60-CYCLE ARC-OVER CHARACTERISTICS—SUSPENSION INSULATORS

The distribution of voltage stress over the units of a string of fifteen standard 10-inch disks and the concentration of stress on certain units, notably those nearest the conductor, is shown by curve *A* in Fig. 10, which is based in the main upon published test data.* At a line voltage of 220 kv., (127 kv. to ground), this concentration reaches a degree which not only interferes seriously with the efficient and economic use of the insulator units, but which brings the stress on the unit next to the conductor to a point higher with respect to its strength than the standards of practise set for 220-kv. service make desirable.

Two methods are recognized as offering relief from this excessive concentration. The first is the grading of the insulator units used in the string. This would be accomplished by making up the string of units of two or more distinct types, differing in size or diameter or in some other feature which would cause them to have different condenser capacities, those with the larger capacities being placed nearest to the conductor. The results of one form of such grading are shown in curve *B*, Fig. 10 which is based upon published test data.* It is evident that by such grading considerable and, for ordinary purposes, ample improvement in voltage distribution can be effected. From a practical standpoint, this expedient involves a certain amount of complication and expense in construction and of expense and inconvenience in operation due to the necessity of maintaining stocks of each of the different types of units

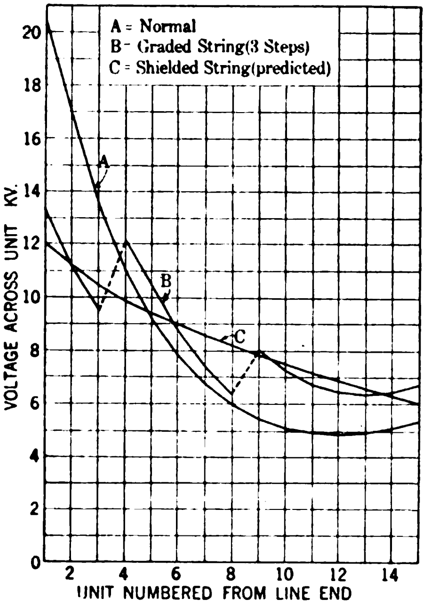

Fig. 10—Typical 60-Cycle Voltage Distribution—Suspension Insulators—220 kv. Grounded Neutral System

and of insuring their proper use in maintenance replacements. This disadvantage, while of some consequence, cannot be regarded as prohibitive in view of the benefits which might be expected to accrue.

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*A. I. E. E. Proceedings 1916 R. H. Marvin, "A New Method of Grading Suspension Insulators."

A second method of relieving this excessive concentration of stress consists in installing below or around the disk nearest the conductor suitably designed metallic shields or rings. The effect of such shields in improving the stress gradient may be even more marked than that of grading the insulator units. The stress distribution obtainable by this method has been predicted in curve *C* of Fig. 10, the values for which have been assumed from the fragmentary test data at hand. The use of such shields or rings at the lower end of the insulator string would obviously tend in itself to increase the requirements for tower clearances, but the shortening of the insulator string, which a successful application of this expedient would justify, might presumably compensate.

In general either grading or shielding or a combination of the two appears to be feasible. Neither would appear to require any very elaborate investigations and tests to determine effective designs free from possibility of secondary complications of any moment. The conditions with the 15-unit string of standard units are so unsatisfactory that probably some alleviating measures should be adopted. Of the two described, probably grading could be developed to a point ready for actual use most quickly and with least experimental investigation. It is wholly possible that a considerable grading effect might be worked out through selection from present commercial types of disks.

A feature of the insulator situation which complicates the question of voltage stress distribution and which will have some effect upon methods of carrying out remedial measures is the fact that in order to obtain adequate mechanical strength, as will be discussed later, two or three strings of standard disks must be used in parallel at suspension points, and proportionately more at tension points. So far as is known, no investigation has been made of the effect of parallel strings upon potential gradient.

The belief is widely entertained that arcing horns or rings or other discharge devices are of sufficient benefit to warrant their use. They would fulfill several functions, the first and primary function being to protect the insulator from the destructive heat of an arc. This function assumes particular importance on a large capacity, lead-grounded neutral system. For this purpose the devices should be so shaped and placed as to hold the arc securely away from the insulator string. Other functions are protection of the conductor from the possible burning by a high-power arc, and reduction of the likelihood of insulator puncture. It may be possible to combine in one device in some effective and economical manner the functions of a discharge horn or ring and of an electrostatic insulator shield.

The foregoing discussion of electrical stresses on insulators refers, as will be noted, to such stresses as may be produced at the normal line frequency of 60 cycles. Under conditions of high-frequency oscillations and of steep wave front phenomena generally, the insulator voltage stress characteristics will be quite different. In particular, the high-frequency voltage stress distribution over an insulator string is understood to follow approximately a straight line characteristic. The importance to be ascribed to high-frequency phenomena as a disturbing factor in 220-kv. operation is a problem of a highly speculative character. Such evidence, however, as is available, and the trend of theoretical opinion, tend toward the conclusion that high-frequency becomes of diminishing relative significance as the line voltage is increased, particularly when transformer neutrals are dead grounded. The suggestion has been offered that, with a line operating near the corona limit, high-voltage surges at high frequency, representing usually small amounts of energy, tend to dissipate themselves in corona, corona dissipation of energy being more rapid at high frequencies. In any event it is believed improbable that a line sufficiently well-insulated to withstand low-frequency high-power disturbances is likely to encounter trouble from high-frequency disturbances.

Mechanical Characteristics of Disk Insulators. The widespread dissatisfaction with the present insulator situation is believed to have arisen largely on mechanical grounds.

A very disturbing feature is the much discussed insulator deterioration. The progressive failure, after a relatively short period of years in service, of the cemented type disk insulator is well recognized and has been almost universally experienced. Existing high-voltage lines are facing the prospect of continuous and difficult tests and expensive maintenance, both attended by interference with operation. Whether the causes be also electrical, chemical or ceramic, the results are unquestionably serious. In this respect, however, the difficulties at 220-kv. would differ from those at low voltage only in the greater number of disks involved.

From the standpoint of deterioration, the non-cemented types of disk insulator, which avoid the effects of dissimilar expansion of the component materials, seem to offer and to be demonstrating marked advantages.

The working stress for standard cemented cap and pin type disks permitted by conservative practise is only about 2500 lb. With the large conductors and extremely heavy design loadings required for 220-kv. service, this low mechanical strength immediately presents itself as an embarrassingly serious limitation. The designs which have been worked out in this study call at normal suspension points for two strings in parallel with spans up to 700 ft. and for three strings in parallel with spans in excess of 700 ft. The complication and expense of hardware and the difficulties involved in clearances are obvious, not to speak of the direct cost of the insulators. If these insulators were to be used at dead-end points, tension assemblies of at least six strings would be required, at the unconservative design load of 2900 lb. per string. A failure in one string, by unbalancing the load distribution, would seriously jeopardize the whole assembly.

For service at dead-end points, however, the unsuitability of the standard disk is so pronounced that it is considered probable that resort would be made at once to an entirely different type of insulator.

Considerable promise is offered by a relatively new type of insulator, a wooden rod insulated with compound and enclosed in a suitably petticoated procelain shell. Any desired mechanical strength can readily be secured in an insulator of this type, so that the full dead-end tension would be carried on one unit. Probably two units would be used in series to obviate an excessively long porcelain tube. Such tension insulators are in limited use on 120-kv. and 150-kv. lines. They are a new development, however, and in the absence of long service demonstration there naturally arises a question as to their electrical permanence. Experiments with somewhat similar types of insulator have shown unfavorable results in the way of disintegration of the wooden rod under long applied high electrical stress. On the other hand, oil insulated wooden rods

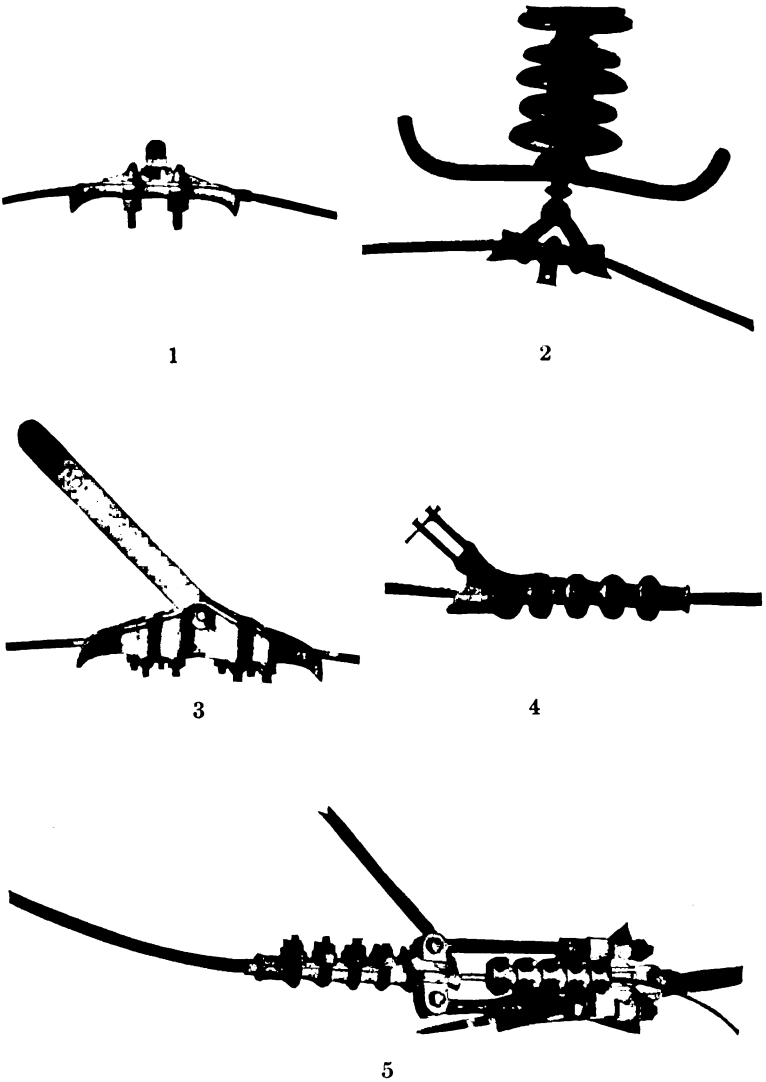

FIG. 11—CONDUCTOR CLAMPS [SILVER]
EXAMPLES OF PREVAILING PRACTISE

Nos. 1, 2 and 3........Suitable Type for Suspension
Nos. 3 and 4 ....Suitable Types for Semi-Tension
No. 5.................Suitable Type for Tension

in circuit breakers have, with few exceptions, been found to be durable. Possibly some other material, less susceptible than wood to disintegration, might be employed for the rod. Any cracking of the porcelain shell or loosening of joints, which would permit escape of the insulating compound, would of course result in failure of the insulator. In the light of present knowledge, however, the lack of service trial appears no more serious than the known complication of huge assemblies of the standard type of disk insulator.

Summarizing the situation as to availability of present commercial disk insulators for 220-kv. service, it is evident that, in addition to known drawbacks, there exists considerable question as to fundamental characteristics which must to some extent be removed before confidence can be established in assumptions made and designs based upon these assumptions. Investigations should be conducted, with possible resultant developments, as to at least three features of the applicability of disk insulators to 220-kv. service, *i. e.:*

1. Tests to confirm or establish the dry and wet flashover characteristics, and accompanying potential gradients, of strings of ten to fifteen disc units, both singly and with several strings in parallel. These characteristics should be investigated both at 60 cycles and at high frequency;
2. Experiments to determine how grading or shielding or both can most effectively be applied to strings of present types of discs;
3. Continued investigation of insulator deterioration problem.

It is to be hoped that those concerned with the design and manufacture of insulators will be inclined to undertake investigations of this character. Of even greater ultimate importance, of course, are efforts looking to the development of a new type of insulator, more efficient electrically, with greater strength mechanically and of unquestionable permanence.

Clamps and Fittings. Reliable and satisfactory clamps are now on the market for composite cables of somewhat smaller sizes. It is not expected that any significant difficulty will be encountered in the design of clamps suitable for a cable of the size proposed. The clamps will presumably be of generally similar design to that of those now in use on some of the highest voltage lines in the country, of which illustration is given in Fig. 11.

In the design of all cable clamps for use at 220 kv., especial care would be required in avoiding of sharp projections, ridges or points which might afford opportunity for formation of corona or static discharges. Sleeve protectors should be used with all types of clamps. At the ends of the clamps, bells of sufficiently large radius should be provided to avoid any chance of conductor crystallization from continued vibration.

In the case of suspension clamps, attention should be given to obtaining long smooth clamping surfaces, and any corrugations should be of large radius. The clamp should hold the cable with sufficient strength to prevent slipping under normal conditions, and in case of conductor breakage slipping should not occur except at the tower adjacent to the break. With the great length of the suspension insulator string, this requirement should not be difficult to meet.

Semi-tension clamps will have an important field of use, since it is the aim to go to extremes in avoiding points where full dead-end tension will come upon insulators. This type of clamp will accordingly be used at smaller angle and stabilizing points. It should hold the conductor, under all conditions, with no appreciable slipping, a requirement which may involve separate clamping of the steel core. A somewhat similar angle or side tension clamp will be needed for use at points where the line makes a considerable horizontal angle.

For tension clamps, the best present practise is to provide for separate clamping of the core, as illustrated in Fig. 11. For large cables worked to their elastic limits, as required for 220-kv. service, this method of clamping will be essential.

Equalizer yokes and connectors present more of a problem than for present lines, since, as noted earlier, even at suspension points two or three insulator strings in parallel would be used, while if disk insulators were to be used at tension points, not less than six parallel strings would be necessary. Whether the present patterns of cast yokes are satisfactory for such heavy duty service is questionable. Pressed steel or some design built up of structural shapes would appear preferable.

Jumpers at dead-end towers will obviously be long, more than 20 ft., and probably some form of jumper guide or anchor will be necessary. This has been satisfactorily accomplished in existing lines by means of auxiliary weights, auxiliary insulator strings or rigid guides of structural steel attached to the yokes.

Transmission Towers. Before proceeding to discussion of the problems of tower types and designs, it may be noted that for present purposes consideration has been confined to single circuit lines, primarily for the reason that at the start a 220-kv. system would be developed gradually, one or two circuits at a time, probably to a considerable extent over different rights-of-way. When, however, 220-kv. becomes established and conditions call for three or more parallel lines, or when networks have been established such that absolutely continuous service of any one line becomes relatively somewhat less important, then the question of using double-circuit structures will deserve careful investigation. The advantages will consist in a considerable saving in tower cost and some saving in right-of-way, against which would lie the relatively minor chance of failure of a structure from extraordinary causes involving two circuits instead of one.

The design of two circuit 220-kv. structures would open interesting possibilities. The large conductor separation, about 20 ft., employed in the accompanying designs, adopted largely as a result of the long insulator strings used, would severely handicap the conventional type of double circuit tower,—three conductors in a generally vertical plane on each side of the tower,—owing to the great height and great weight of steel required. A shorter insulator would tend to reduce this handicap. There are other feasible types of double-circuit tower for 220-kv. service, in some respects more promising, in particular a tower with three legs transverse to the line carrying all six conductors in a horizontal plane. This type makes the high transverse strength easy to obtain, and suggests the possibility of building two legs to carry one circuit initially and adding the third leg and the second circuit later. The design of a double-circuit tower would, of course, be determined primarily by economy of steel. A discussion of structures for multiple circuit lines is, however, beyond the scope of the present study.

The choice of structure material, whether wood, or steel, is primarily one of total economy, considering first cost, depreciation and maintenance. The long economic life which presumably a 220-kv. line would represent, causes durability of material to assume even greater importance than in present practise, so that for most localities, wood construction would not be economical, even assuming that the requisite strength for the heavy loads could be secured without resorting to unduly short spans.

As to type of structure to be employed, the conventional *rigid* tower has been adopted as the most available for construction in the immediate future. The rigid tower type of line has been thoroughly studied and tested by experience, and when properly designed, its performance record has been satisfactory, at least with the smaller conductors and lighter loadings thus far used. It is recognized, of course, that the very great stresses existing in such a line as is here proposed tends to disturb the balance of considerations which has deter-

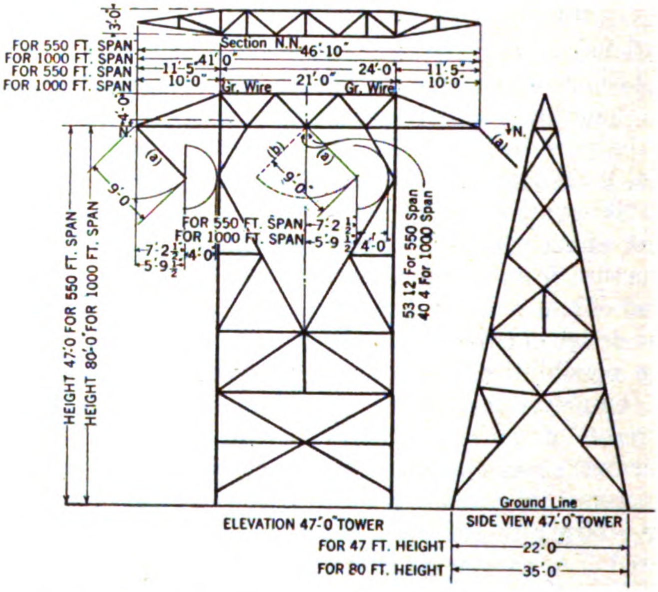

FIG. 12—220-KV. STEEL TRANSMISSION TOWER—CLEARANCE DIAGRAM TYPE A (SUSPENSION)—FOR VERTICAL ANGLE 5 DEG. AND HORIZONTAL ANGLE 0 DEG. TO 2 DEG. (FOR DESIGN LOADING AND STRESSES SEE TABLE III

CONDITIONS CAUSING MAXIMUM SWING OF INSULATORS TAKEN FOR DETERMINING TOWER DIMENSIONS

Position	Span	Horizontal Angle Turned by Conductors	Wind	Ice	Temp.
a	550	——> 2 deg.	——> 8 lb.	0 in.	0 deg.
b	550	<—— 2 deg.	<—— 8 lb.	0 in.	0 deg.

TABLE III
DESIGN LOADING AND STRESSES
TYPE A TOWER (SUSPENSION)
VERTICAL ANGLE 5 DEG. AND HORIZONTAL ANGLE 0 DEG. TO 2 DEG.
CONDUCTOR, ALUMINUM 716,000 CIR. MIL.—STEEL 92,900 CIR. MIL.
GROUND WIRE 5/8 IN. STEEL STRAND SUSPENSION INSULATORS
WIND 8 LB. ICE 1½ IN. AT 0 DEG. FAHR.
(FOR TYPE A TOWER CLEARANCE DIAGRAM SEE FIG. 12)

Span (Normal and max. allowable with maximum angles)	550 ft.	700 ft.	800 ft.	1000 ft.
Height of cross arm above ground	47 ft.	57 ft.	63 ft.	80 ft.
Transverse Loading				
Wind on tower	750	850	1,000	1,250
Wind on 3 conds. with 1½ in. ice at 2.69 lb. per ft	4,400	5,650	6,440	8,050
Wind on 2 gr. wires with 1½ in ice. at 2.42 lb. per ft	2,650	3,400	3,860	4,850
Pull, 3 conds. due to 2 deg. hor. angle	1,800	1,800	1,800	1,800
Pull, 2 gr. wires due to 2 deg. hor. angle	1,200	1,200	1,200	1,200
Total load	10,800	12,900	14,300	17,150
Test load—125 per cent	13,500	16,000	18,000	21,500

Torsional Loading

It is assumed that one conductor is broken and the pull of the conductor in the adjoining span is decreased due to the tendency of the insulator string to swing in the direction of the pull.

Assumed maximum load	8,000	9,000	10,000	11,000
Test load—125 per cent	10,000	11,300	12,500	13,800
Vertical Loading (At each conductor and ground wire support)				
Weight of conductor at .09 lb. per ft	500	600	750	900
Weight of 1½ in. ice at 4.72 lb. per ft	2,600	3,300	3,800	4,750
Due to 5 deg. vertical angle	1,500	1,500	1,500	1,500
Insulators and hardware	400	400	400	400
Men	200	200	200	200
Repair tackle	800	800	800	800
Total load at one support	6,000	6,800	7,450	8,550
Test load—125 per cent	7,500	8,500	9,300	10,700

Design Stresses

Above test loads include all factors of safety so that structural steel should be stressed as follows:

	Test load	Working load max. condition
In tension	30,000 lb. per sq. in.	24,000
In compression	$\left(30{,}000 - \frac{100\,L}{R}\right)$ lb. per sq. in.	$\left(24{,}000 - \frac{80\,L}{R}\right)$
Bolts in shear	25,000 lb. per sq. in.	20,000
Bolts in bearing	50,000 lb. per sq. in.	40,000

Values of L/R to be used shall be:
a. For main members not greater than 120
b. For secondary members not greater than 200
c. For redundant members not greater than 250

Minimum thickness of metal ¼ in. All material to be galvanized.

Test loads as specified for transverse, torsional and vertical loading to be applied separately.

mined the present rigid tower type of line design, and further study, in conjunction with actual experience in 220-kv. construction, may later indicate that greater economy is obtainable with a different type of construction. For immediate purposes, however, it has been deemed that a conservative attitude should be adopted toward innovations not specifically called for by the conditions of 220-kv. service.

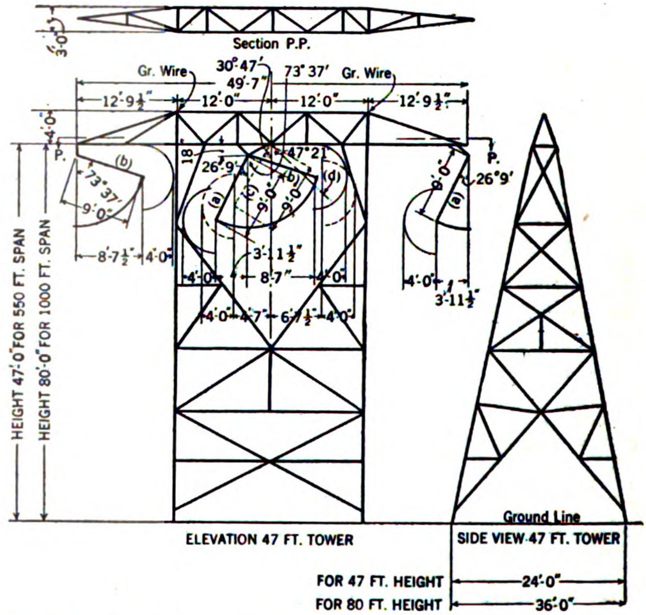

FIG. 13—220-KV. STEEL TRANSMISSION TOWER—CLEARANCE DIAGRAM—TYPE B (SUSPENSION)—FOR VERTICAL ANGLE 10 DEG. AND HORIZONTAL ANGLE 2 DEG. TO 10 DEG. (FOR DESIGN LOADING AND STRESSES SEE TABLE IV)

CONDITIONS CAUSING MAXIMUM SWING OF INSULATORS TAKEN FOR DETERMINING TOWER DIMENSIONS

Position	Span	Hroizontal Angle Turned by Conductors	Wind	Ice	Temp.
a	1000	——> 2 deg. plus	<—— 8 lb.	0 in.	120 deg.
b	550	10 deg.	——> 8 lb.	0. in.	0 deg.
c	1000	0 deg.	<—— 8 lb.	0 in.	0 deg. or 120 deg.
d	550	2 deg. minus	——> 8 lb.	0 in.	0 deg.

It is growing practise in heavy line construction to provide a

TABLE IV
DESIGN LOADING AND STRESSES
TYPE B TOWER (SUSPENSION)

VERTICAL ANGLE 10 DEG. AND HORIZONTAL ANGLE 2 DEG. TO 10 DEG.
CONDUCTOR, ALUMINUM 716,000 CIR. MILS. STEEL 92,900 CIR. MILS.
GROUND WIRE $^{5}/_{8}$ IN. STEEL STRAND SUSPENSION OR SEMI-TENSION INSULATORS
WIND 8 LB. ICE 1½ IN. AT 0 DEG. FAHR.
(FOR TYPE B TOWER CLEARANCE DIAGRAM SEE FIG. 13)

Span (Normal)	550 ft.	700 ft.	800 ft.	1000 ft.
Span (maximum allowable with maximum angles)	700 ft.	900 ft.	1000 ft.	1200 ft.
Height of cross arm above ground	47 ft.	57 ft.	63 ft.	80 ft.
Transverse Loading				
Wind on tower	850	1,000	1,250	1,500
Wind on 3 conds. with 1½ in. ice at 2.69 lb. per ft.	5,600	7,250	8,050	9,700
Wind on 2 gr. wires with 1½ in. ice at 2.42 lb. per ft.	3,350	4,350	4,850	5,800
Pull 3 conds. due to 10 deg. horizontal angle	9,000	9,000	9,000	9,000
Pull 2 gr. wires due to 10 deg. horizontal angle.	6,000	6,000	6,000	6,000
Total load	24,800	27,600	29,150	32,000
Test load—135 per cent	33,500	37,300	39,400	43,200

Torsional Loading

It is assumed that two conductors are broken and that the pull of the conductors in the adjoining span causes unbalanced loading in the tower.

Load at any one conductor or ground wire support	17,300	17,300	17,300	17,300
Test load—135 per cent	23,400	23,400	23,400	23,400
Vertical Loading (At each conductor and ground wire support)				
Weight of conductor at 0.9 lb. per ft.	600	850	900	1,100
Weight of 1½ in. ice at 4.72 lb. per ft.	3,300	4,250	4,700	5,700
Due to 10 deg. vertical angle	3,000	3,000	3,000	3,000
Insulators and hardware	400	400	400	400
Men	200	200	200	200
Repair tackle	800	800	800	800
Total load at one support	8,300	9,500	10,000	11,200
Test load—135 per cent	11,200	12,800	13,500	15,100

Design Stresses (Same for Towers Types C. D. and E. Tables V, VI and VII)

Above test loads include all factors of safety so that structural steel should be stressed as follows:

	Test loads	Working load max. condition
In tension	30,000 lbs. per sq. in.	22,000
In compression	$\left(30{,}000 - \frac{100\,L}{R}\right)$ lbs. per sq. in.	$\left(22{,}000 - \frac{75\,L}{R}\right)$
Bolts in shear	25,000 lbs. per sq. in.	18,500
Bolts in bearing	50,000	37,000

Values of L/R to be used shall be:
a. For main members not greater than 120
b. For secondary members not greater than 200
c. For redundant members not greater than 250

Minimum thickness of metal $^{1}/_{8}$ in. All material to be galvanized.

Test loads as specified for transverse, torsional and vertical loading to be applied separately.

series of standard towers of different strengths, adapted to safe and economical use under varying conditions of span lengths and angles. The extremely heavy loading basis assumed for a 220-kv. line makes it feasible, and desirable from the standpoint of economy of steel, to carry this differentiation to a greater extent than has been customary heretofore. The tower design studies which follow are based upon a series of five standard types of tower for use under the varying conditions presented by a 220-kv. line over a rolling terrain.

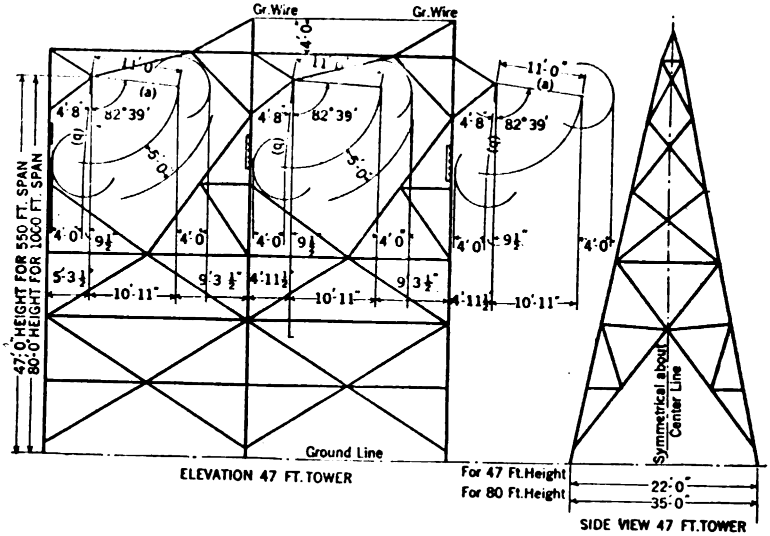

Fig. 14—220-kv. Steel Transmission Tower—Clearance Diagram—Type C (Side Tension)—For Vertical Angle 15 deg. and Horizontal Angle 10 deg. to 25 deg. (For Design Loading and Stresses See Table V)

Conditions Causing Maximum Swing of Insulators Taken for Determining Tower Dimensions

Position	Span	Horizontal Angle Turned by Conductors	Wind	Ice	Temp.
a	550	——> 25 deg.	——> 8 lb.	0 in.	0 deg.
b	1000	10 deg.	<—— 8 lb.	0 in.	120 deg.

The determination of economic balance between height and weight of towers and normal length of span is an interesting and a fundamentally important problem. Studies of tower designs and of this economic balance for four different normal span lengths are shown in some detail in Figs. 12, 13, 14, 15 and

16, with accompanying data in Tables III, IV, V, VI and VII. The procedure followed in carrying out this study of economic span length will be described briefly. As a basis of study a typical section of profile, as shown in Fig. 17, (a section 23.3 miles long from an actual surveyed route), was selected as a fair example of average 220 kv. line location in rolling country,

TABLE V
DESIGN LOADING AND STRESSES
TYPE C TOWER (SIDE TENSION)
VERTICAL ANGLE 15 DEG. AND HORIZONTAL ANGLE 10 DEG TO 25 DEG.
CONDUCTOR. ALUMINUM 716,000 CIR. MIL.—STEEL 92,900 CIR. MIL.
GROUND WIRE $^5/_8$ in. STEEL STRAND
SUSPENSION OR SEMI-TENSION INSULATORS
WIND 8 LB.—ICE 1½ in. AT 0 DEG. FAHR.
(FOR TYPE C TOWER CLEARANCE DIAGRAM SEE FIG. 14)

Span (Normal)	550 ft.	700 ft.	800 ft.	1000 ft.
Span (max. allowable with maximum angles)	900 ft.	1100 ft.	1200 ft.	1400 ft.
Height of crossarm above ground	47 ft.	57 ft.	63 ft.	80 ft.
Transverse Loading				
Wind on tower	1,200	1,400	1,500	1,750
Wind on 3-conds. with 1½ in. ice at 2.69 lb. per ft.	7,250	8,875	9,700	11,300
Wind on 2-ground wires with 1½ in. ice at 2.42 lb. per ft.	4,350	5,325	5,800	6,750
Pull, 3 conductors due to 25 deg. horizontal angle	22,500	22,500	22,500	22,500
Pull, 2 ground wires due to 25 deg. horizontal angle	14,500	14,500	14,500	14,500
Total load	49,800	52,600	54,000	56,800
Test load, 135 per cent	67,200	71,000	72,900	76,700

Torsional Loading

It is assumed that two conductors and one ground wire are broken and that the pull of the unbroken conductor and ground wire in the adjoining span causes unbalanced loading on the tower.

Load at any one conductor support	17,300	17,300	17,300	17,300
Test load—135 per cent	23,400	23,400	23,400	23,400
Load at any one ground wire support	16,000	16,000	16,000	16,000
Test load—135 per cent	21,600	21,600	21,600	21,600
Vertical Loading (at each Conductor and Ground Wire Support)				
Weight of cond. at 0.9 lb. per ft.	810	990	1,080	1,260
Weight of 1½ in. ice at 4.72 lb. per ft.	4,250	5,200	5,670	6,600
Due to 15 deg. vertical angle	4,500	4,500	4,500	4,500
Insulator and hardware	1,200	1,200	1,200	1,200
Men	400	400	400	400
Repair tackle	1,200	1,200	1,200	1,200
Total load at one support	12,360	13,490	14,050	15,160
Test load—135 per cent	16,700	18,200	18,900	20,500

Design Stresses (Same as for Type B Tower, See Table 4) and the economic study was based upon this profile. For each of four normal span lengths; *i. e.*, 550 ft., 700 ft., 800 ft. and 1000 ft., four actual approximate line designs, based each upon its own set of specific tower locations, was carried out, and the cost of each line was estimated. These costs, as plotted in Fig. 18, show maximum economy with normal spans of 800 ft. with

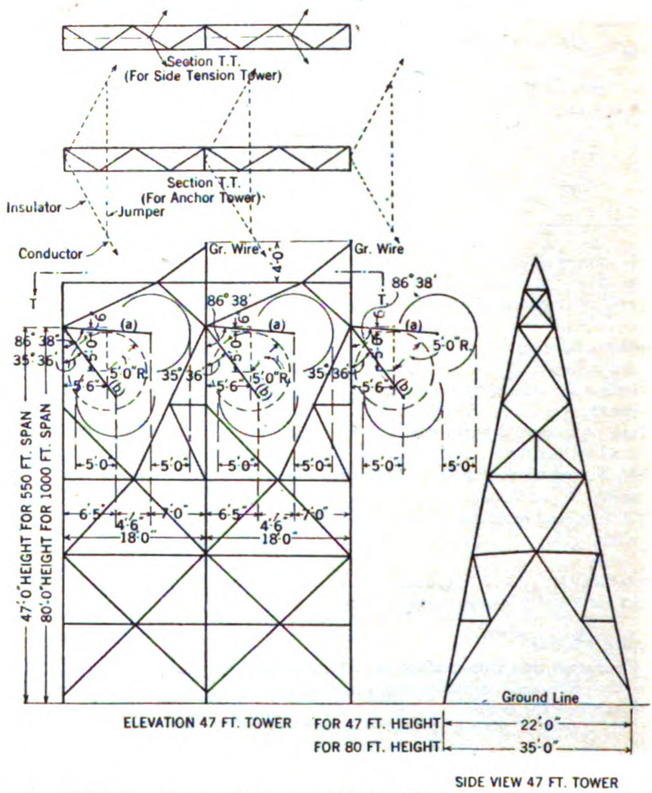

Fig. 15—220-kv. Steel Transmission Tower—Clearance Diagram—Type D (Side Tension and Anchor)—Vertical Angle 25 deg.—Horizontal Angle (Side Tension) 25 deg. to 60 deg. (Anchor) 60 deg. to 90 deg. (For Design Loading and Stresses See Table VI)

Conditions Causing Maximum Swing of Insulators Taken for Determining Tower Dimensions

Position	Span	Horizontal Angle		Ice	Temp.
		Turned by Conductors	Wind		
a	550	→ 60 deg.	→ 8 lb.	0 in.	0 deg.
b	1000	25 deg.	← 8 lb.	1½ in.	32 deg.

TABLE VI
DESIGN LOADING AND STRESSES

Type D Tower (Side Tension and Anchor)
Vertical Angle 25 Deg.
Horizontal Angle (Side Tension) 25 Deg. to 60Deg., (Anchor) 60 Deg. to 90 Deg.
Conductor, Aluminum 716,000 Cir. Mil.—Steel 92,900 Cir. Mil.
Ground Wire $^5/_8$ in. Steel Strand
Suspension, Semi-Tension or Tension Insulators
Wind 8 Lb.—Ice 1½ in. at 0 Deg. Fahr.
(For Type D Tower Clearance Diagram See Fig. 15)

Span (Normal)	550 ft.	700 ft.	800 ft.	1000 ft
Span (maximum allowable with maximum angles)	1100 ft.	1300 ft.	1400ft.	1600 ft.
Height of gross arm above ground	47 ft.	57 ft.	63 ft.	80 ft.
Transverse Loading				
Wind on tower	1,200	1,400	1,500	1,750
Wind on 3 conductors with 1½ in. ice at 2.69 lb. per ft.	8,875	10,500	11,300	12,900
Wind on 2 ground wires with 1½in ice at 2.42 lb. per ft.	5,325	6,300	6,800	7,750
Pull 3 conductors due to 90 deg. horizontal angle	73,400	73,400	73,400	73,400
Pull 2 gr. wires due to 90 deg. horizontal angle.	45,300	45,300	45,300	45,300
Total load	134,100	136,900	138,300	141,100
Test load—135 per cent	181,000	184,800	186,700	190,500
Longitudinal Loading (Line terminal tower)				
Pull due to 3 conductors	51,900	51,900	51,900	51,900
Pull due to 2 ground wires	32,000	32,000	32,000	32,000
Total load	83,900	83,900	83,900	83,900
Test load—135 per cent	113,300	113,300	113,300	113,300

Torsional Loading

It is assumed that two conductors and two ground wires are broken and the pull of the conductors and ground wires in the adjoining span causes unbalanced loading in the tower.

Load at anyone conductor support	17,300	17,300	17,300	17,300
Test load—135 per cent of actual	23,400	23,400	23,400	23,400
Load at any one ground wire support	16,000	16,000	16,000	16,000
Test load—135 per cent of actual	21,600	21,600	21,600	21,600
Vertical Loading (At each conductor and ground wire support)				
Weight of conductors at 0.9 lb. per ft.	1,000	1,200	1,300	1,450
Weight of 1½ in. ice at 4.72 lb. per ft.	5,200	6,150	6,600	7,550
Due to 25 deg. vertical angle	7,300	7,300	7,300	7,300
Insulators and hardware	1,200	1,200	1,200	1,200
Men	400	400	400	400
Repair tackle	1,200	1,200	1,200	1,200
Total load at one support	16,300	17,450	18,000	19,100
Test load—135 per cent of actual load	22,000	23,600	24,300	25,800

Design Stresses (Same as for Type B Tower, See Table IV) the rigid type of tower assumed, while longer spans or shorter spans are more expensive. The 800 ft. normal span was selected as a basis for further studies.

The method of carrying out these line designs involved, first, determining the height of tower corresponding to the span length selected. To determine this height, a ground clearance of 25 ft. under design loading was assumed (corresponding with an 800-ft. span to about 35 ft. at 60 deg. fahr) and a sag-clearance template developed for the aluminum-steel conductor used. On level ground, for the 25 ft. clearance, this template gave the standard tower heights for the four normal span lengths under consideration as 47 ft., 57 ft., 63 ft. and 80 ft. For each height of tower, the five standard designs were developed in outline and, with the sag-clearance template, tower locations were spotted on the typical profile selected. With the locations determined, the required type of tower was selected from the

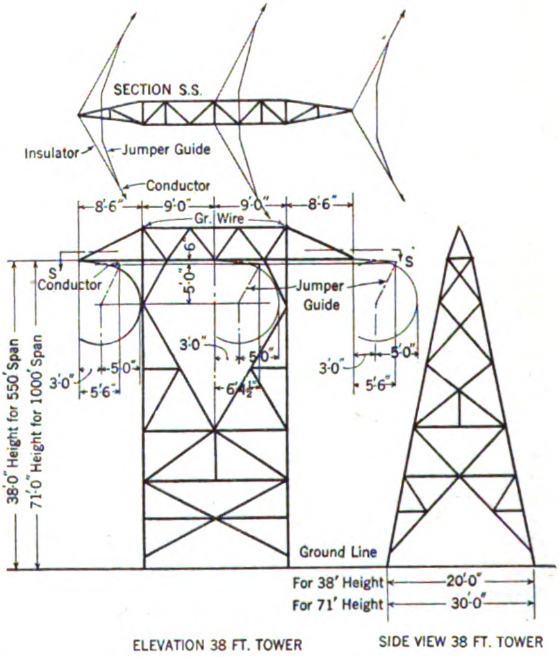

Fig. 16—220-kv. Steel Transmission Tower—Clearance Diagram—Type E (Anchor)—Horizontal Angle (Side Tension) 0 deg. to 15 deg. (Anchor) 0 deg. to 60 deg. (For Design Loading and Stresses See Table VII)

TABLE VII
DESIGN LOADING AND STRESSES
TYPE E TOWER (ANCHOR)

VERTICAL ANGLE 0 DEG. TO 15 DEG. AND HORIZONTAL ANGLE 0 DEG. TO 60 DEG.
CONDUCTOR ALUMINUM 716,000 CIR. MIL.—STEEL 92,900 CIR. MIL.
GROUND WIRE $^5/_8$ IN. STEEL STRAND
TENSION INSULATORS
WIND 8 LB.—ICE 1½ IN. AT 0 DEG. FAHR.
(FOR TYPE E TOWER CLEARANCE DIAGRAM SEE FIG. 16)

Span (normal)	550 ft.	700 ft.	800 ft.	1000 ft.
Span (maximum allowable with maximum angles)	1000 ft.	1200 ft.	1300 ft.	1500 ft.
Height of cross arm above ground	38 ft.	48 ft.	54 ft.	71 ft.
Transverse Loading				
Wind on tower	850	1,000	1,250	1,500
Wind on 3 conds. with 1½ in. ice at 2.69 lb. per ft.	8,070	9,700	10,500	12,100
Wind on 2 gr. wires with 1½ in ice at 2.42 lb. per ft.	4,830	5,800	6,300	7,300
Pull—3 conductors due to 60 deg. horizontal angle	51,900	51,900	51,900	51,900
Pull—2 gr. wires due to 60 deg. horizontal angle	32,000	32,000	32,000	32,000
Total load	97,650	100,400	101,950	104,800
Test load—135 per cent	131,800	135,500	137,600	141,500
Longitudinal Loading (Line terminal tower)				
Pull due to 3 conductors	51,900	51,900	51,900	51,900
Pull due to 2 ground wires	32,000	32,000	32,000	32,000
Total load	83,900	83,900	83,900	83,900
Test load—135 per cent	113,300	113,300	113,300	113,000

Torsional Laoding

It is assumed that two conductors and two ground wires are broken and the pull of the conductors and ground wires in the adjoining span causes unbalanced loading in the tower.

Load at any one conductor support	17,300	17,300	17,300	17,300
Test load—135 per cent	23,400	23,400	23,400	23,400
Load at any one ground wire support	16,000	16,000	16,000	16,000
Test load—135 per cent	21,600	21,600	21,600	21,600
Vertical Loading (at each conductor and ground wire support)				
Weight of conductors at 0.9 lb. per ft.	900	1,080	1,170	1,350
Weight of 1½ in. ice, at 4.72 lb. per ft.	4,700	5,670	6,136	7,080
Due to 15 deg.—vertical angle	4,500	4,500	4,500	4,500
Insulators and hardware	1,200	1,200	1,200	1,200
Men	400	400	400	400
Repair tackle	1,200	1,200	1,200	1,200
Total load at one support	12,900	14,050	14,600	15,700
Test load—135 per cent	17,400	19,000	19,700	21,200

Design Stresses (Same as for Type B Tower, See Table IV.

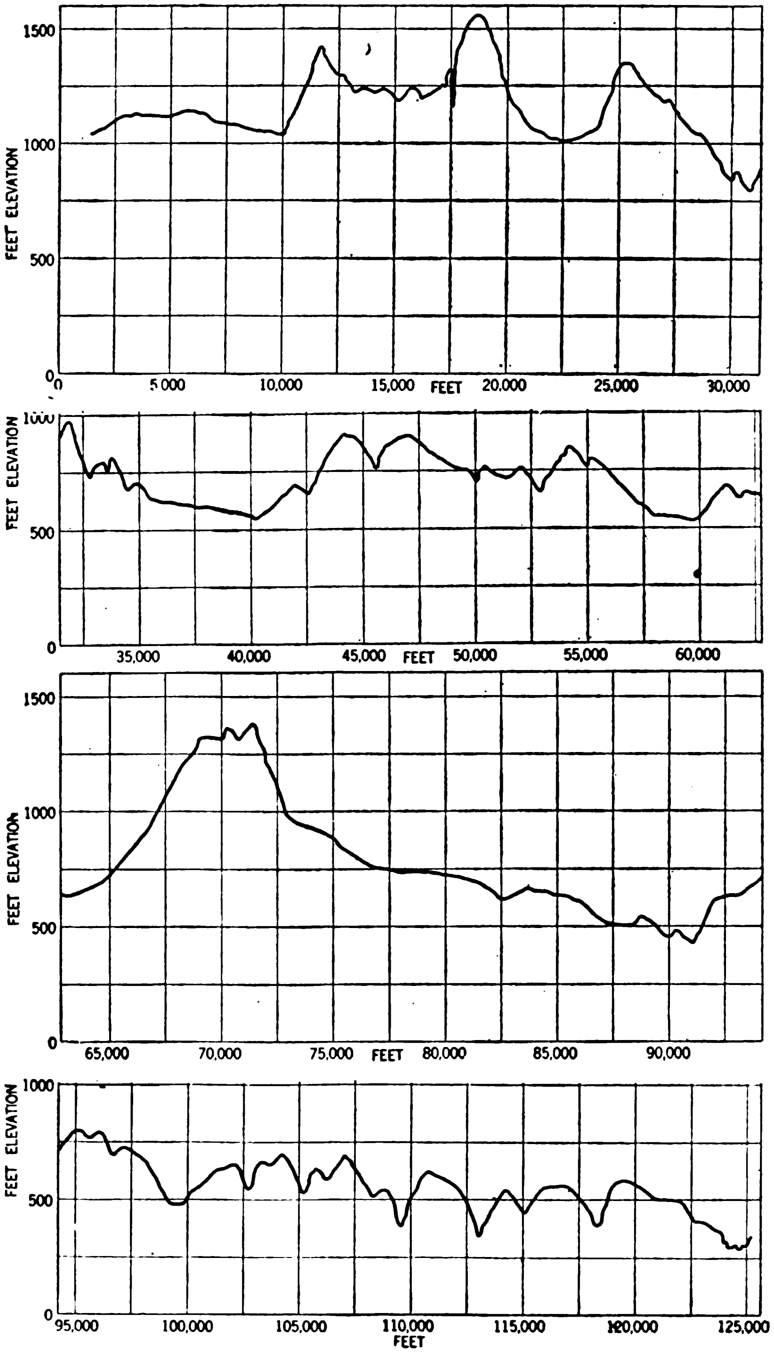

FIG. 17—SECTION OF PROFILE OF TYPICAL TRANSMISSION RIGHT OF WAY USED AS BASIS FOR 220-KV. LINE STUDIES TO DETERMINE ECONOMIC SPAN

TABLE VIII

220-KV. TRANSMISSION LINE STUDIES PRELIMINARY ESTIMATE TO DETERMINE ECONOMIC SPAN. SELF-SUSTAINING, HORIZONTAL ARRANGEMENT, SINGLE CIRCUIT. STEEL TOWERS

Article	550-foot span						700-foot span						800-foot span						1,000-foot span					
	Quan.	Unit		Total			Quan.	Unit		Total			Quan.	Unit		Total			Quan.	Unit		Total		
		Used	Cost	Item	Div.	Group		Used	Cost	Item	Div.	Group		Used	Cost	Item	Div.	Group		Used	Cost	Item	Div.	Group
1. TOWERS	1	mi 1	....	....	....	$10,455	1	mi. 1	....	....	....	$ 9,880	1	mi 1	....	....	....	$ 9,895	1	mi. 1	....	....	....	$11,230
A. *Cost f. o. b. Factory*	10.60	mi.	830	....	8,800	....	8.018	mi.	1,053	....	8,450	....	6.810	mi.	1,246	....	8,490	....	5.180	mi.	1,889	....	9,770	....
1. Type A	8.490	each	708	6,020	....	....	6.510	each	890	5,800	....	....	5.350	each	1,040	5,565	....	....	3.800	each	1,535	5,840	....	....
2. " B	1.770	"	1,130	2,000	....	....	1.120	"	1,450	1,625	....	....	1.160	"	1,710	1,990	....	....	1.080	"	2,435	2,630	....	....
3. " C	0.172	"	1,740	300	....	....	0.216	"	2,200	475	....	....	0.172	"	2,530	435	....	....	0.173	"	3,570	620	....	....
4. " D	0.084	"	3,600	300	....	....	0.086	"	3,950	340	....	....	0.086	"	4,400	380	....	....	0.085	"	5,980	510	....	....
5. " E	0.084	"	2,160	180	....	....	0.086	"	2,460	210	....	....	0.042	"	2,820	120	....	....	0.042	"	4,095	170	....	....
B. Freight	732	cwt.	0.28	....	205	....	703	cwt.	0.28	....	195	....	712	cwt.	0.28	....	200	....	813	cwt.	0.28	....	230	....
C. Handling and hauling	36.6	ton	6.00	....	220	....	35.1	ton	6.00	....	210	....	35.6	ton	6.00	....	215	....	40.7	ton	6.00	....	245	....
D. Assembling	36.6	"	10	....	365	....	35.1	"	9.00	....	315	....	35.6	"	8.00	....	285	....	40.7	"	7.00	....	285	....
E. *Excavating and Grading*	....	mi.	....	....	345	....	....	mi.	....	....	261	....	....	mi.	....	....	259	....	....	mi.	....	....	225	....
1. Type A	8.49	each	30	255	....	....	6.51	each	30	195	....	....	5.35	each	35	187	....	....	3.800	each	40	152	....	....
2. " B	1.77	"	40	70	....	....	1.12	"	40	45	....	....	1.16	"	45	53	....	....	1.080	"	50	54	....	....
3. " C	0.172	"	50	10	....	....	0.216	"	50	10	....	....	0.172	"	55	10	....	....	0.173	"	60	10	....	....
4. " D	0.084	"	60	5	....	....	0.086	"	60	6	....	....	0.086	"	65	6	....	....	0.085	"	70	6	....	....
5. " E	0.084	"	55	5	....	....	0.086	"	55	5	....	....	0.042	"	60	3	....	....	0.042	"	65	3	....	....
F. *Setting Footings*	....	mi.	....	....	170	....	....	mi.	....	....	167	....	....	mi.	....	....	180	....	....	mi.	....	....	180	....
1. Earth	10.35	twr.	10	105	....	....	7.63	twr.	10	76	....	....	6.60	twr.	15	99	....	....	4.97	twr.	15	75	....	....
2. Concrete	0.250	"	260	65	....	....	0.280	"	326	91	....	....	0.210	"	381	80	....	....	0.210	"	500	105	....	....
a- Type A	....	each	....	....	....	....	....	each	....	....	....	....	....	each	....	....	....	....	....	each	....	....	....	....
b- " B	....	"	....	....	....	....	....	"	....	....	....	....	....	"	....	....	....	....	....	"	....	....	....	....
c- " C	0.082	"	250	20 –	....	....	0.108	"	300	33 –	....	....	0.085	"	350	30 –	....	....	0.085	"	450	38 –	....	....
d- " D	0.084	"	300	25 –	....	....	0.086	"	350	30 –	....	....	0.085	"	400	34 –	....	....	0.085	"	500	42 –	....	....
e- " E	0.084	"	275	20 –	....	....	0.086	"	325	28 –	....	....	0.042	"	375	16 –	....	....	0.042	"	475	20 –	....	....
G. *Erecting*	....	mi.	....	....	295	....	....	mi.	....	....	242	....	....	mi.	....	....	232	....	....	mi.	....	....	224	....
1. Erecting	10.60	twr.	18	190	....	....	8.02	twr.	20	161	....	....	6.81	twr.	22	150	....	....	5.18	twr.	28	146	....	....
2. Backfilling	10.60	"	10	105	....	....	8.02	"	10	81	....	....	6.81	"	12	82	....	....	5.18	"	15	78	....	....
M. Miscellaneous	10.60	each	5	....	55	....	8.02	each	5	....	40	....	6.81	each	5	....	34	....	5.18	"	5	....	26	....
2. INSULATORS (Suspension)	1	mi. 1	....	....	....	$ 4,390	1	mi. 1	....	....	....	$ 3,300	1	mi. 1	....	....	....	$ 3,575	1	mi. 1	....	....	....	$ 2,870
A. Cost f. o. b. factory	1,379	each	2.30	....	3,170	....	1,040	each	2.30	....	2,400	....	1,152	each	2.30	....	2,651	....	920	each	2.30	....	2,117	....
B. Suspension clamps	28	"	4.00	....	112	....	22	"	4.00	....	88	....	18	"	4.00	....	72	....	13	"	4.00	....	52	....
C. Semi-tension clamps	3	"	5.00	....	15	....	2	"	5.00	....	10	....	2	"	5.00	....	10	....	2	"	5.00	....	10	....
D. Tension clamps	6	"	6.00	....	36	....	2	"	6.00	....	12	....	2	"	6.00	....	12	....	2	"	6.00	....	12	....
E. Equalizer yokes	116	"	4.00	....	465	....	86	"	4.00	....	345	....	45	"	4.00	....	180	....	42	"	4.00	....	168	....
F. Ex. H. equalizer yokes	14	"	6.00	....	85	....	11	"	6.00	....	65	....	42	"	6.00	....	252	....	32	"	6.00	....	192	....
G. Links	65	"	1.00	....	65	....	47	"	1.00	....	48	....	45	"	1.00	....	45	....	42	"	1.00	....	42	....
H. Clevis eyes and shackles	259	"	0.50	....	130	....	194	"	0.50	....	97	....	202	"	0.50	....	101	....	161	"	0.50	....	81	....
I. Arcing horns	62	"	0.50	....	30	....	59	"	0.50	....	30	....	51	"	0.50	....	26	....	29	"	0.50	....	15	....
J. Freight	180	cwt.	0.40	....	72	....	127	cwt.	0.40	....	51	....	140	cwt.	0.40	....	56	....	112	cwt.	0.40	....	45	....
K. Handling and hauling	9.0	ton	6.00	....	55	....	6.4	ton	6.00	....	40	....	7.0	ton	6.00	....	42	....	5.6	ton	6.00	....	34	....
L. Assembling and erecting	1,379	disc	0.10	....	140	....	1,040	disc	0.10	....	104	....	1,152	disc	0.10	....	116	....	920	disc	0.10	....	92	....
M. Miscellaneous	1,379	"	0.01	....	15	....	1,040	"	0.01	....	10	....	1,152	"	0.01	....	12	....	920	"	0.01	....	10	....
3. CONDUCTORS	1	mi. 1	....	....	....	$ 250	1	mi. 1	....	....	....	$ 200	1	mi. 1	....	....	....	$ 175	1	mi. 1	....	....	....	$ 150
Stringing only	1	" "	250	....	250	....	1	" "	200	....	200	....	1	" "	175	....	175	....	1	" "	150	....	150	....
4. GROUND WIRES	1	mi. 1	....	....	....	$ 75	1	mi. 1	....	....	....	$ 70	1	mi. 1	....	....	....	$ 60	1	mi. 1	....	....	....	$ 50
Stringing only	1	" "	75	....	75	....	1	" "	70	....	70	....	1	" "	60	....	60	....	1	" "	50	....	50	....
5. RIGHT OF WAY	1	mi. 1	....	....	....	$ 3,500	1	mi. 1	....	....	....	$ 3,350	1	mi. 1	....	....	....	$ 3,250	1	mi. 1	....	....	....	$ 3,000
	10.60	twr.	330	....	3,500	....	8.02	twr..	420	....	3,350	....	6.08	twr.	535	....	3,250	....	5.18	twr.	580	....	3,000	....
6. TOTAL MAT'L. AND LABOR (*)	1	mi. 1	....	....	....	$18,670	1	mi. 1	....	....	.....	$16,800	1	mi. 1	....	....	....	$16,955	1	mi.1	....	....	....	$17,300

(OVER)

TOWER-DATA

Article	Unit	550-foot span					700-foot span				
Type of tower	....	A	B	C	D	E	A	B	C	D	E
Avg. span on typical profile (a)	ft.	485	526	700	700	700	655	701	620	620	620
Towers typical profile (b)	no.	197	41	4	2	2	151	26	5	2	2
Towers per mile	no.	8.490	1.770	0.172	0.084	0.084	6.510	1.120	0.216	0.086	0.086
Height of tower	ft.	47	47	47	47	38	57	57	57	57	48
Weight of tower	lb.	5,900	9,400	14,500	30,000	18,000	7,400	12,100	18,000	33,000	20,500
Cost of steel per lb.	c.	12	12	12	12	12	12	12	12	12	12
" " tower	$	708	1,130	1,740	3,600	2,160	890	1,450	2,200	3,950	2,460
Max. allow. hor. angle	0	2	10	25	90	60	2	10	25	90	60
Max. allow. vert. angle	0	5	10	15	25	15	5	10	15	25	15
Weight of towers per mile	lb.	50,100	16,600	2,500	2,500	1,500	48,200	13,500	4,000	2,800	1,800
" " " " " total	"	....	....	73,200	....	....	....	....	70,300	....	....

Article	Unit	800-foot span					1000-foot span				
Type of tower	....	A	B	C	D	E	A	B	C	D	E
Avg. span on typical profile (a)	ft.	787	739	743	743	743	1,015	1,060	657	657	657
Towers typical profile (b)	no.	124	27	4	2	1	88	25	4	2	1
Towers per mile	no.	5.350	1.160	0.172	0.086	0.042	3.800	1.080	0.173	0.085	0.042
Height of tower	ft.	63	63	63	63	54	80	80	80	80	71
Weight of tower	lb.	8,760	14,250	21,050	36,700	23,500	12,810	20,250	29,810	49,780	34,120
Cost of steel per lb.	c.	12	12	12	12	12	12	12	12	12	12
" " tower	$	1,040	1,710	2,528	4,405	2,821	1,536	2,435	3,572	5,980	4,095
Max. allow. hor. angle	0	2	10	25	90	60	2	10	25	90	60
Max. allow. vert. angle	0	5	10	15	25	15	5	10	15	25	15
Weight of towers per mile	lb.	46,880	16,530	3,620	3,160	990	48,690	21,880	5,160	4,236	1,434
" " " " " total	"	....	....	71,180	....	....	....	....	81,300	....	....

INSULATOR AND HARDWARE DATA

Article	550-foot span										
Type of tower	A		B		C		D		E		Total
Towers per mile	8.490		1.770		0.172		0.084		0.084		
No. insul. strings	2		6		4		2 × 6		2 × 6		
Total number	per		per		per		per		per		
	Tower	Mile	Tower	Mile	Tower	Mile	Tower	Mile	Tower	Mile	
Insulators (c)	90	764	270	478	204	35	612	51	612	51	1,397
Susp. clamps	3	25	d 3	3	....	....	....	....	....	....	28
Semi-ten. clamps	....	....	d 3	3	....	....	....	....	....	....	3
Tension clamps	....	....	....	....	e 3	5	6	0.5	6	0.5	6
Equalizer yokes	6	51	30	53	12	2	60	5	60	5	116
Ex. H. equal. yoke	....	....	6	11	6	1	12	1	12	1	14
Links	....	....	30	53	12	2	60	5	60	5	65
Clevis Eyes	18	153	48	85	30	5	96	8	96	8	259
Arcing horns	6	34	12	21	8	1	24	2	24	2	62

Article	700-foot span										
Type of tower	A		B		C		D		E		Total
Towers per mile	6.510		1.120		0.216		0.086		0.086		
No. insul. strings	2		6		4		2 × 6		2 × 6		
Total number	per		per		per		per		per		
	Tower	Mile	Tower	Mile	Tower	Mile	Tower	Mile	Tower	Mile	
Insulators (c)	90	586	270	302	204	44	612	55	612	53	1,040
Susp. clamps	3	20	d 3	1.7	....	....	....	....	....	....	22
Semi-ten. clamps	....	....	d 3	1.7	....	....	....	....	....	....	2
Tension clamps	....	....	....	....	e 3	0.7	6	0.5	6	0.5	2
Equalizer yokes	6	39	30	34	12	2.6	60	5.1	60	5.2	86
Ex. H. equal. yoke	....	....	6	7	6	1.3	12	1.1	12	1.1	11
Links	....	....	30	34	12	2.6	60	5.1	60	5.2	47
Clevis Eyes	18	117	48	54	30	6.5	96	8.2	96	8.3	194
Arcing horns	6	39	12	14	8	1.7	24	2.0	24	2.1	59

Article	800-foot span										
Type of tower	A		B		C		D		E		Total
Towers per mile	5.350		1.160		0.172		0.086		0.042		
No. insul. strings	3		6		4		2 × 6		2 × 6		
Total number	per		per		per		per		per		
	Tower	Mile	Tower	Mile	Tower	Mile	Tower	Mile	Tower	Mile	
Insulators (c)	135	723	270	314	204	36	612	53	612	26	1,152
Susp. Clamps	3	16	d 3	1.8	....	....	....	....	....	....	18
Semi-ten. clamps	....	....	d 3	1.8	....	....	....	....	....	....	2
Tension clamps	....	....	....	....	e 3	0.5	6	0.5	0.6	0.3	2
Equalizer yokes	....	....	30	35	12	2.1	60	5.1	60	2.5	45
Ex. H. equal. yoke	f 6	32	6	7	6	1.1	12	1.0	12	0.5	42
Links	....	....	30	35	12	2.1	60	5.1	60	2.5	45
Clevis eyes	24	128	48	56	30	5.2	96	8.2	96	4.0	202
Arcing horns	6	32	12	14	8	1.4	24	2.0	24	1.0	51

Article	1000-foot span										
Type of tower	A		B		C		D		E		Total
Towers per mile	3.800		1.080		0.173		0.085		0.042		
No. insul. strings	3		6		4		2 × 6		2 × 6		
Total number	per		per		per		per		per		
	Tower	Mile	Tower	Mile	Tower	Mile	Tower	Mile	Tower	Mile	
Insulators (c)	135	513	270	292	204	36	612	53	612	26	920
Susp. Clamps	3	11	d 3	1.6	....	....	....	....	....	....	13
Semi-ten. clamps	....	....	d 3	1.6	....	....	....	....	....	....	2
Tension clamps	....	....	....	....	e 3	0.5	6	0.5	6	0.3	2
Equalizer yokes	....	....	30	32.4	12	2.1	60	5.1	60	2.5	42
Ex. H. equal. yoke	6	23	6	6.5	6	1.1	12	1.0	12	0.5	32
Links	....	....	30	32.4	12	2.1	60	5.1	60	2.5	42
Clevis eyes	24	91	48	51.9	30	5.2	96	8.2	96	4.0	161
Arcing horns	6	23	12	1.3	8	1.4	24	2.0	24	1.0	29

NOTES:—(*) Part affected by span only. (a) The average span for the various types of towers is the resultant of applying the template for the normal span to 23.3 miles of actual profile. (b) In determining the number and kind of towers, shown in this horizontal row, a template for given normal span was applied to an actual profile of a line 23.3 miles in length. (c) 15 discs per insulator string on Towers A and B; 17 discs per insulator string on Towers C, D and E. d-on ½ B Towers. e-special. f.3 way.

known angles and span lengths involved at each tower site. The results of this study are given in Table VIII, showing for each normal span length the numbers required of such type of tower and a comparison of line costs, exclusive of conductors and ground wires for which the costs would be constant.

It is believed that this method of analysis, *i. e.*, using an actual or typical profile, affords a more accurate and reliable basis of determining economic normal span lengths and tower heights than the simpler method of considering only straight lines on a level profile. Further refinements in the way of studying the effect of using a different height or more than one height for the heavier towers might be attempted, but it is questionable whether they would be warranted, in view of the many uncertainties involved, particularly in field work. It will be noted that this study of economic balance is carried out on the basis of the high prices obtained in early 1918. A lower price level would have some effect upon the results, as would a different size or type of conductor and a different type of insulator, particularly if it were stronger and shorter.

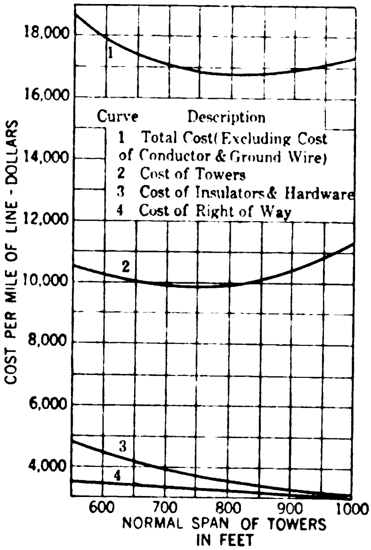

Fig. 18—220 kv. Transmission Line—Determination of Economic Span—Relation of Span Length to First Cost

In the tower designs study has been made of the general form, of the dimensions of the main members and of approximate weights, but the designs have not been carried into the details. No designs have been prepared of tower footings, side hill extensions, etc., which are distinctly contingent upon local conditions and which have no direct or material effect upon the general line designs. Figs. 12 to 16 show the general types of towers proposed, with details as to dimensions, and as to working and test loads. Estimated weights are shown in Fig. 19. The working loads were computed from the design loadings under the most extreme conditions of angles and span lengths for which the tower is to be used. In addition to the main margin of safety provided in the design loading, a further margin is introduced in the difference between working and test loads, *i. e.*, 25 per cent for suspension towers and 35 per cent for angle and dead-end towers. It may be noted that a still further margin of safety will result when a tower is employed in a location imposing less than its maximum designed working load, a condition which will obtain for the major percentage of the line.

After the study of tower locations was carried out, it became evident that there was economic justifications for a sixth type of tower, a special light weight type to be used primarily on short spans in tangents. This tower is illustrated in Fig. 20. An economic improvement in the design shown for this light weight type might be effected by shortening the tower to correspond to the smaller sags obtaining in short spans.

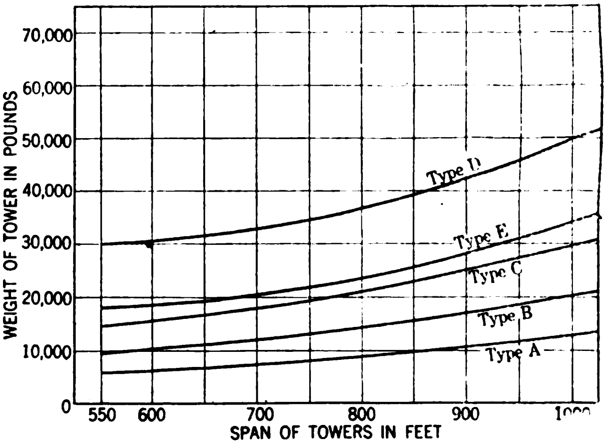

FIG. 19—220-KV. SINGLE-CIRCUIT STEEL TRANSMISSION TOWERS— ESTIMATED WEIGHTS

Type A—See Fig. 12; Type B—See Fig. 13; Type C—See Fig. 14; D—See Fig. 15; Type E—See Fig. 16

It is believed desirable that sample towers of each design should be subjected to thorough experimental tests before quantity production is started. Tower design involves approximations, and the heavy loads and consequent great weights of 220-kv. towers justify more than usual effort to obtain an economically consistent design. In the method of making such tests, more elaborate and refined methods than hitherto employed might be developed to advantage. It is desirable to ascertain not only the point and manner of failure under test, but also the simultaneous stress conditions existing in all important tower members.

Tower foundations will be largely a special problem for each locality. The conditions governing present practise will apply, the only new considerations being the unusually heavy loads involved and the strong emphasis which must be placed upon dependability. In general, for most soils, earth foundations would probably be adequate for straight suspension towers, while concrete foundations would be necessary for full tension and heavy angle towers and probably for semi-tension and

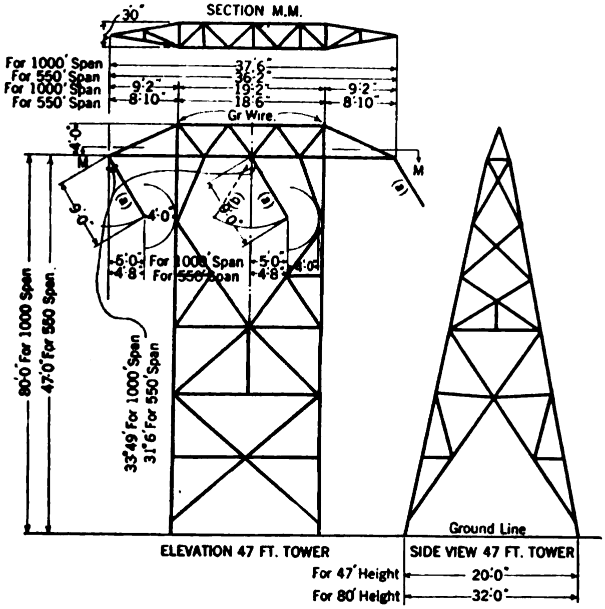

Fig. 20—220 kv. Steel Transmission Towers—Clearance Diagram—Type AA (Suspension)—For Vertical Angle 5 deg. and Horizontal Angle 0 deg.

Conditions Causing Maximum Swing of Insulators Taken for Determining Tower Dimensions

Position	Span	Horizontal Angle Turned by Conductors	Wind	Ice	Temp.
a	1000	0 deg.	8 lb.	0 in.	0 or 120 deg.
b	1000	0 deg.	8 lb.	in.	0 or 120 deg.

light angle towers. Where concrete foundations are used, the tower should be carefully grounded.

Protection of towers from deterioration is of more than ordinary importance owing to the great investment represented by a 220-kv. line and the long economic life which it presumably will possess. Galvanizing would seem essential and it should be heavy and carefully applied. Protection of joints and of steel at the ground line will call for every feasible precaution.

DESIGN FEATURES OF 220-KV. STATION AND SUBSTATION EQUIPMENT

While, in general, the character and arrangement of equipment at generating stations and substations is not a part of the primary scope of this paper, there are certain features in connection with this equipment which directly concern the feasibility and the economic and general advantages of transmitting power at this high voltage. Brief consideration of these features is essential to a study of 220-kv. transmission.

The problems of interest, new or assuming particular importance in connection with equipment for a 220-kv. system, are of two types, those arising directly from the high voltage *per se* and those resulting from the relatively enormous capacities and amounts of power involved in a system large enough to call for the use of such a voltage. The handling of electrical potentials of 220,000 volts does not appear to involve any disturbing complications or uncertainties. In fact, the manufacturers do not recognize that any serious problem exists. Current design principles and materials now in ordinary use will be employed, the principal difference from present high voltage equipment being the greater amounts of insulation and the larger clearances required. The step to 220 kv. is relatively no greater than that previously taken from 66 kv. to 110 kv., or from 110 kv. to 154 kv. Certain of the manufacturers have already developed designs, and assert readiness to undertake commercial production of 220-kv. equipment on short notice.

The problems attendant upon the huge capacities which use of 220-kv. transmission makes possible and feasible,—generating stations of several hundred thousand kilowatts, interconnected systems of a half million or a million kilowatts,—are distinctly of a major order. From the purely physical standpoint, the principal problems are those of switching and protection from short circuit stresses. Both of these, it is believed, can be handled satisfactorily. The more general questions of simplicity and reliability of operation and of efficiency and general economy attain a new order of importance and will probably lead to some significant departures from present practise in smaller scale systems.

Design for such large capacities and high voltage centers around one cardinal principle, *simplicity and intrinsic strength of equipment rather than flexibility and external protective measures*. The principal equipment units represent such high values, both in service and in investment, that the maximum of continuous service should be obtained, and more careful attention and large expense are fully justified in assuring virtual elimination of failures in service. The accompanying arrangement diagram of an assumed typical system, Fig. 21. indicates the extent to which the aim of simplicity is advocated in reduction of bus arrangements to a simple and even rudimentary form and in elimination of superfluous oil switches. In particular, attention may be called to the fact that no spare units, either generators or transformers, are provided, and none are contemplated. The investment in the large units will be so large that outage should be represented only by the irreducible minimum of apparatus troubles and maintenance, not by

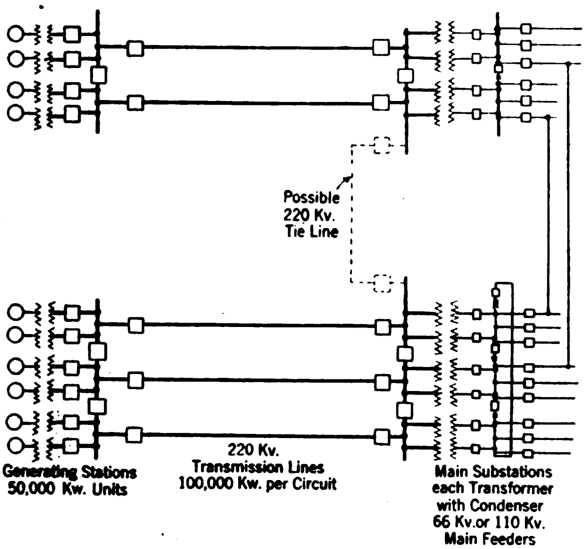
Possible 220 Kv. Tie Line
Generating Stations 50,000 Kw. Units
220 Kv. Transmission Lines 100,000 Kw. per Circuit
Main Substations each Transformer with Condenser 66 Kv.or 110 Kv. Main Feeders

FIG. 21—TYPICAL ARRANGEMENT DIAGRAM—220-KV. SYSTEM

the nearly continuous idleness of spare equipment. This complete omission of reserve units of major apparatus is of course predicated upon adequate reserve capacity being available in local generating stations near the load centers, as has been discussed previously.

The obtaining of strength and high reliability of equipment is primarily a problem of construction economics rather than of system design, although the latter is an important element. Certain features of the problem are high reactance of generators and transformers, ample insulation of transformers and an efficient oil circulation system, high mechanical strength of oil switches, avoidance of low-voltage buses and low-voltage paralleling, and an effective and dependable system of relay sectionalizing.

Study of the design and operation of 220-kv. equipment has brought out certain general principles or features which may be noted before taking up consideration of particular pieces of apparatus:

1. *High Voltage Switching.* All line switching, automatic or manual, should be done on the *high voltage* side of transformers. This statement may come as a jolt to certain established ideas, but the further the switching problem has been studied, the more clearly does it appear that high voltage switching is not only more simple but is more safe. The amounts of power involved, particularly under abnormal conditions, are so tremendous that the current values obtaining at lower voltages impose switch duties and heavy stresses generally which could be handled only with great difficulty and at an expense materially higher than would be required at 220-kv., where the currents involved are relatively small.

From the standpoint of automatic sectionalizing and continuity of service, high-tension switching is obviously desirable, since defective circuits in tripping out will leave the transformers in service to continue supplying load from parallel circuits or alternative routes.

2. *Transformer Connections.* All 220-kv. transformers, on the high voltage side, should be connected in Y with the neutral grounded, as shown graphically in Fig. 22. The high potentials involved and the great lengths of line to be interconnected constitute conditions which might easily result in uncontrolable surges if the high-voltage circuits were isolated from ground. While grounding at one end of a line would materially alleviate

these conditions, more adequate stabilization of voltage, with consequent greater economy in equipment and security in operation, can be obtained by grounding at all points where transformers are located. It may be of interest to note that the voltage stresses on a 220-kv. grounded system (normal voltage to ground 127 kv.), will be less than for some certain existing isolated delta systems. There obtains also the general advantage of grounded Y operation that automatic sectionalizing is made more positive and reliable, a vital consideration on so large and important a transmission system.

The neutral should be grounded without resistance. The purpose of a resistance in the neutral connection is to limit current flow into a ground on a line or in apparatus. For lower voltages where excessive magnetic stresses would result, the expedient is frequently desirable, but for 220 kv., where the short circuit current values are relatively small and provision for handling the resultant stresses relatively simple, any benefit which might be gained would not be justified by the expense and complication which the use of resistance would involve, and it would in any case be more than offset by the impairment of the function of the ground in stabilizing potentials.

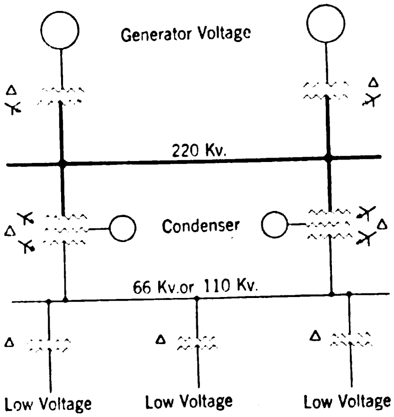

FIG. 22—DIAGRAM OF TRANSFORMER CONNECTIONS—220-KV. SYSTEM

3. *Protective Equipment.* No equipment of any character is contemplated for protection against over-voltages. As a fundamental principle it is believed that investment can be

applied more effectively and with greater ultimate economy in providing greater margins of safety in the apparatus against the stresses which are likely to be encountered, than in attempting to shield weaker apparatus by methods now known. For such a voltage as 220 kv., protective equipment would be proportionately more costly than in case of lower voltages and its efficacy more questionable.

High-voltage protective devices are of two general types, those intended to protect against abnormal potentials at normal or low frequencies, and those intended to protect against high-frequency surges or steep wave fronts which might give rise to localized high-potential stresses in the windings of transformers and in other apparatus. For protection against high potentials, electrolytic arresters and other so-called lightning arresters have been used extensively in systems of lower voltage. On a 220-kv. system with dead-grounded neutrals, it is not believed that any abnormal potentials are likely to be encountered which apparatus insulation cannot and should not be able to withstand. For protection against high-frequency effects, series reactances have been used and elaborate arrangements of reactances, condensers and resistances have been proposed. While probably high-frequency constitutes more of a real danger, it is considered that it can be met most effectively and economically by providing adequate insulation strength.

220-*kv. Transformers.* The questions which naturally will be the first to arise in consideration of transformers for a 220-kv. system are those of size of units and three-phase vs. single-phase units, the two questions being to some extent interdependent.

Considerations of simplicity in station arrangement and of economy in operation favor, in general, transformers of the largest size permitted by the conditions of each installation or by limitation of manufacture. Theoretically there seems no limit to the capacity of a transformer unit, but beyond a certain capacity the provision of strength to withstand the mechanical stresses of short circuit current becomes a matter of such complication and expense that an economical limit will come into effect. At the present stage of the art, the manufacturers advocate that transformers be not attempted beyond 50,000 to 60,000 kv-a. for three-phase units, or 35,000 to 40,000 kv-a. for single-phase units. Transformer cores and windings for these capacities can be shipped assembled from the factories. Advance quotations and estimates from manufacturers show progressively lower unit costs up to these sizes. The economic advantage of large units depends not so much, however, upon lower unit costs as upon considerations of space, bus construction, number of switches, etc., all of which involve relatively less expense for larger units. The adverse difference in cost of handling facilities is not great.

As to choice between three-phase and single-phase units, from the standpoint of simplicity and cheapness of installation, three-phase units would be preferable. As to factory cost and efficiency, there appears on the basis of information at present available to be little difference, three-phase transformers being somewhat cheaper for same capacity of bank and somewhat more expensive for same capacity of unit. The great weight which should be given the principle of providing high intrinsic reliability of main units, rather than providing spare units, materially reduces one of the principal advantages claimed for single-phase transformers, that of the less capacity required in reserve units. For large installations, three-phase units offer advantages. For relatively small substations, it is believed that equally satisfactory service at less cost can be rendered by a bank of two three-phase units as compared with one bank of single-phase units with a spare. Certainly a bank of three three-phase units would be superior, and the cost should be no greater.

At generating stations, operating and economic considerations strongly favor the generator and its transformer equipment as a unit. If the generator capacity should exceed the practicable limit of three-phase transformer capacity, there apparently would be a close margin of choice between using a single-phase bank or two three-phase transformers operating as a bank and controlled by one circuit breaker.

In past high-voltage practise, probably one of the most troublesome features in operation has been the bushings. Experience indicates, however, that satisfactory bushing designs have now been developed and can readily be applied to 220-kv. service. Bushings will of course be identical and interchangeable for transformers and oil switches. Transformers will have but one high-voltage bushing per phase, the neutral ends of the winding not being insulated from the tank.

The saving in equipment costs which has been noted as one of the reasons for selecting grounded Y rather than delta for the 220-kv. transformer connections, is very marked in the case of transformers. Insulation is less throughout the whole transformer and extra insulation is required at only one end of the windings rather than at both, cores and tanks are correspondingly smaller, efficiency is higher, amount of oil required is less and bushings are lighter and shorter.

The large sizes of installations involved in a 220-kv. system, together with the necessity for careful attention to maintaining insulation strength and transformer reliability generally, will not improbably result in a radical change in the present method of handling and cooling transformer oil, *i. e.*, the abandonment of cooling of oil in each transformer and gravity circulation of oil through the windings in favor of forced oil circulation and external cooling. The idea of external cooling is by no means new, but whereas for the relatively small installations of present practise it appears to involve unjustified complication and expense, for installations of the size here contemplated this condition will probably be reversed. The apparent advantages, briefly summarized, are as follows:

a. Tanks smaller and cheaper due to elimination of cooling coils and smaller volume of oil in transformer.

b. Positive circulation of oil and possibility of more accurately directing it in its flow through the windings to the points needed and in amounts needed.

c. More effective cooling due to low temperature which may be obtained in incoming oil and more rapid circulation.

d. Oil kept absolutely dry and always at maximum insulation strength due to possibility of sealing oil system against the atmosphere, a most important advantage for extra high voltage operation.

e. Oil may readily be filtered continuously to any extent desired.

f. System as a whole more reliable and probably cheaper.

Such an external transformer oil system might be developed to handle all oil in a common system, or to keep the oil for each transformer bank separate. The common system would be somewhat cheaper and simpler, and hence preferable if adequate precautionary measures could be worked out to prevent contamination of the entire oil system as a result of a failure in one transformer. The system in either case would include cooling devices located wherever desired, probably in a pond or stream, oil pumps, filters, a storage tank at a suitable elevation to provide circulating head, and at some point an expansion device which would maintain a reasonable pressure regulation under conditions of varying volume of the enclosed oil due to temperature changes. The entire oil system would be effectively sealed against the atmosphere. Vital parts of the oil system would presumably be installed in duplicate, the expense being small in proportion to total cost of the station.

A system of external cooling of oil may, at generating stations, open the way for a significant increase in overall efficiency. Transformer losses will amount to about 1.25 per cent of station output. Possibly half of this heat may be recovered from the oil by passing it, on its way to the final cooling coils, through some device installed in the steam system between the condensers and the economizers. While no studies have been made of the economic feasibility of such a scheme, the physical possibility opens an interesting problem.

220-*kv. Oil Circuit Breakers.* A system such as here contemplated, with huge generating stations, numbers of them interconnected, and large synchronous condenser capacity at substations, will necessarily involve unprecedented concentrations of energy at switching points, particularly in case of short circuits. The high duty required of circuit breakers to meet this condition is a vitally important problem in the design of such a system. It is, as has been noted, early evident in a study of the switching problem, that switching should be done wherever possible on the high-voltage side of transformers, since the high voltage can more easily be handled than the high currents at lower voltage. Two hundred and twenty-kv. short-circuit current values are not extreme, and in a 220-kv. circuit breaker the large clearances and switch openings necessarily involved by the high voltage contribute directly to giving the rupturing capacity required by the current to be handled.

Magnitudes of 220-kv. circuit-breaker duty will, of course, depend upon the size and arrangement of the 220-kv. system. With a system of the capacity and arrangement shown in Fig. 21, the duty of a circuit breaker at the bus of either the larger generating station or the larger substation would, according to approximate calculations, be from 1,000,000 kv-a. to 1,500,000 kv-a., depending upon the length of the 220-kv. lines. At the smaller generating station or substation the duty would be somewhat less. No difficulty should be involved in obtaining circuit breakers for this duty at 220-kv. With the gradual expansion which might be expected in such a power supply system, with other generating stations and substations added, extensive interconnections made in secondary networks and probably a considerable 220-kv. network established, there might be expected circuit breaker duties of 3,000,000 to 4,000,000 kv-a. Manufacturers foresee no insurmountable difficulty in designing 220-kv. circuit breakers for duties of this magnitude. The duty on such an extensive system might be reduced by adoption of some degree of sectionalized operation of the 220-kv. lines, but it is hoped that the need for such an expedient can be avoided.

Two types of circuit breakers have been offered by the manufacturers for 220-kv. high duty service. One type consists of a massive circuit breaker, each phase in one tank of heavy boiler plate, with two breaks in series for moderate duty and four breaks in series for heavy duty. The tank is built according to the principles of boiled design to withstand the internal pressure generated by the opening under oil of the rated kv-a. loads, as predetermined by test and calculation. The tank is not designed to withstand explosions in the space above the oil, this hazard being eliminated by provision for thorough ventilation or other expedients to prevent formation of explosive mixtures in this space.

Another type of 220-kv. circuit breaker consists of two breaks in series per tank, one such tank being used for conditions of moderate duty and two tanks in series for heavy duty. The four series breaks in the double-unit circuit breaker are operated simultaneously. These tanks likewise are designed to withstand the stresses generated under the oil under conditions of maximum duty, but in this case the full stresses are not permitted to come upon the tank. Each break is located in a carefully designed explosion chamber, of relatively small diameter and of any required strength, which confines the initial force of the explosion and serves both to reduce the pressures which can be set up in the main tank, and to utilize this force as an aid in extinguishing the arc. With this type of circuit breaker, one tank unit would probably be installed initially when the 220-kv. system was small, and a second unit added later when the growth of the system brought about power concentrations in excess of the rupturing capacity of the single unit.

It is believed that either of these types of circuit breaker will give satisfactory service on a 220-kv. system.

220-*kv. Air-Break Disconnectors.* Air-break disconnectors for 220-kv. service present a problem which, while distinctly of a minor character in relation to the general problems of 220-kv. construction, is troublesome, and for which no wholly satisfactory designs have thus far been offered. The difficulties attending development of such disconnectors do not concern feasibility, since a disconnector which will operate acceptably can be built after existing designs, but concern rather avoidance of unnecessary expense, space requirements, and general complication. The problem is one of making a firm high-capacity contact, without incurring hazard or undue inconvenience to operators or to service, under any sort of weather conditions, between two elements supported by long, heavy, cumbersome and somewhat fragile insulators.

These 220-kv. disconnectors would be used to disconnect an oil switch from or connect it to a live line or bus. It is not contemplated that such a switch need be able to break the charging current of a 220-kv. transformer, although a switch capable of this duty would be valuable if it could be developed. It might be used to take the place of a 220-kv. circuit breaker in some cases or to give added flexibility in cases where transformer circuit breakers were not provided.

In situations where disconnectors need not be operated with either pole alive, as for instance between transformers and transformer circuit breakers at the generating station in Fig. 21, the cumbersome 220-kv. disconnector would not be needed, and some form of simple readily removable link would be used.

Generating Station Arrangement. Simplicity should be the dominating principle in the electrical layout of the generating station. The generator and its transformer should be a unit and there should be no low-voltage bus and no low-voltage paralleling. For stations of the size contemplated, a bus at generator voltage would involve such tremendous duty on oil switches, such elaborate sectionalizing reactances and, in general, such expense and hazard to reliability of operation, all without any material benefit, that it unquestionably should be omitted.

Preferably, although not necessarily, a specific bank of generators should be assigned to each 220-kv. circuit, thus enabling segregation of circuits at the generating stations, if desired. The economic capacity of a 220-kv. circuit is roughly 100,000 kw. to 150,000 kw., so that usually this would mean two, or possibly three, generators per circuit. In case conditions governing generating station practise should favor larger generators, say of the order of 100,000-kw., and if satisfactory units of this capacity should be developed, simple station layout would be possible by using one generator to each 220-kv. circuit.

In case it were necessary for a 220-kv. generating station to deliver power also at a lower voltage, for instance 66 kv., it would still be desirable to avoid a bus at generator voltage. The preferable arrangement for such a station would be a bus at each line voltage, each fed by its own generators. These two busses might or might not, depending upon the particular conditions obtaining, be interconnected by transformers.

The omission of the low-voltage bus would not complicate the problem of auxiliary station service, since good practise already provides that such service shall be supplied from a special generator rather than from the station bus.

Synchronizing at 220-kv. can be effectively accomplished, it is believed, by an adaptation of the static synchroscope.

Main Substation Arrangement. Two hundred and twenty-kv. substation layout will be influenced largely by the particular local conditions of each installation. The usual type will probably serve to step down from 220-kv. to a secondary transmission voltage, such as 66 kv. or 110 kv. In such a case it will, in general, be necessary to have both a primary and a secondary bus system,—at 220 kv. a simple bus with sectionalizing circuit breakers, at secondary voltage, where greater flexibility would seem desirable, probably a ring bus. Owing to the high current values which would obtain at the secondary voltage, (it should be kept in mind that the large condenser capacity will aggravate short circuit conditions), it appears advisable to provide sectionalizing reactances in this bus.

Synchronous condensers, of such capacity as may be demanded by length of 220-kv. line, amount, load factor and power factor of load, will be provided for each transformer bank. In the usual case, these condensers will be connected to a third winding in the main transformers. This method of connecting the condensers appears to be simpler, cheaper, and equally reliable as compared with connecting the condensers to separate transformers on the low-voltage bus, although the corrective effect would not apply to the secondary windings. Three-winding 220-kv. transformers, with the tertiary winding of 50 per cent of the capacity of the 220-kv. winding, would cost about 15 per cent more than two-winding transformers. The voltage of this tertiary winding and of the condenser would be as high as may be found practicable for satisfactory operation of this type of apparatus.

In cases where the secondary substation voltage were within range of generator operation, 11 kv., 13 kv. or 22 kv., the condensers might be connected directly to the secondary bus.

Relay System. The station and substation arrangements which have been proposed are predicated upon a relay system which may be depended upon for effective and consistent automatic operation, *i. e.*, for insuring that a faulty piece of apparatus, transmission line, or low-voltage feeder will be cut out correctly, promptly and in such a manner as to avoid interruption to the other elements of the system. Complete multiple operation of all 220-kv. apparatus, stations and lines is feasible only with a thoroughly dependable relay system. In view of the encouraging developments in the relay field during recent years, and of the fact that on such an important system much effort can be concentrated in working out a solution, it seems reasonable to assume that an adequate relay system will be available.

Complete 220-kv. multiple operation is essential to obtaining full economy and service reliability from the system, and any resort to sectionalized operation, due to lack of adequate relays, unreliability of circuit breakers or any other cause, should be looked upon as a distinct failure to develop the full possibilities of the system and as a temporary expedient to be dispensed with as soon as possible. With complete multiple operation, transmission lines are used to maximum efficiency, there is full flexibility in shifting of load between generators or stations, and, with dependable automatic disconnecting, trouble in any part of the system may be isolated with a minimum of disturbance to load.

CONSTRUCTION COST

The following estimates are intended to give an indication of the installation cost of construction carried out along the lines of the assumptions and recommendations in this paper. Local conditions, of course, may require a considerable variation in arrangement and cost, particularly of substation apparatus. These estimates are based on early 1919 prices, and apply to station capacities of 200,000 kw. and larger at 220 kv.

Step-Up Substation. Outdoor transforming and switching structures and equipment (220-kv. apparatus and connections only), installations and indirect expense.		$8 to $9 per kw.
Step-Down Substation. Outdoor transforming and switching structures and equipment (does not include low tension feeder bus or feeder switching equipment) synchronous condensers of capacity for length of connected lines, building, control equipment, installation and indirect expense....		$15 to $20 per kw.
Transmission Lines. Single circuit-steel towers-suspension insulators.		
Towers........................	$8000 per mi.	
Insulators and Hardware........	2800 per mi.	
Conductors and Ground Wire....	5000 per mi.	
Special Structures...............	1000 per mi.	
Right-of-way....................	3000 per mi.	
Indirect expense...............	3700 per mi.	
Total....................		$23,500 per mi.
Total Cost 220-kv. Transmission.		
100 mi.........................		$40 to $45 per kw.
200 mi.........................		60 to 65 per kw.
300 mi.........................		80 to 85 per kw.

CONCLUSIONS

1. It is generally recognized that the country's industrial advancement will require increasingly great amounts of electric power, particularly in view of the relation between use of power and unit productiveness of labor, and that this power must be supplied in accordance with a rational policy of conservation of our greatest national asset, our fuel resources. This points to the necessity of large scale transmission of power from distant points of generation at the energy sources, coal fields and water powers.

2. Two hundred and twenty kv. appears a logical choice for such large-capacity, long-distance transmission, which is clearly beyond the economic range of present transmission voltages. Two hundred and twenty kv. is high enough to meet pending

requirements in power supply evolution but not so far beyond existing practise as to involve question of its immediate feasibility.

3. Design of a 220-kv. system brings up important problems, new in character or significance. These problems are due rather more to the large amounts of power involved than to the high voltage.

4. Two hundred and twenty-kv. power supply will require unprecedentedly high service standards, load factors will be high, particularly at the start, and the frequency should be 60 cycles. For full economy the load for each 220-kv. circuit should be 100,000 kw. or higher.

5. The selection of type and size of conductor is an important economic problem involving a balance of many factors. Corona does not enter as an especially serious limitation owing to the large size of conductors otherwise required. Research is needed as to best method of stringing conductors.

6. Insulators of present commercial disk types can be made to give acceptable service, but there is need of an insulator more efficient electrically, stronger mechanically and of unquestioned durability. There is opportunity for valuable research and development work in this field.

7. The familiar single-circuit rigid type of steel tower appears to be most conservative for immediate use, owing to its reliability having been demonstrated by experience. The field offers promising possibility for development of other types of single-circuit and multiple-circuit towers. The economical span length (here taken as 800 ft. normal), may vary with the factors of each situation. A series of standard towers of graduated weights will be advisable.

8. The basic idea of 220-kv. station and substation design is simplicity and intrinsic strength of equipment, rather than flexibility and external protective measures.

9. Transformer connections should be on Y 220-kv. side with neutral dead grounded. Development of 220-kv., large capacity transformers presents no undue difficulties. Frequently the design might advantageously employ forced oil circulation with external cooling. Present types of bushings, suitably adapted, seem satisfactory for 220-kv. service.

10. The 220-kv. system should be laid out for multiple operation and switching should be done at 220-kv. A thoroughly dependable and carefully coordinated relay system is a basic requirement.

11. Development of circuit breakers presents no serious difficulty from standpoint of voltage, and it is believed that proposed designs will be adequate for the duty which will be demanded.

12. At generating stations each generator and its step-up transformer bank should be treated as a unit. There would be no low-voltage bus and no low-voltage circuit breaker.

13. At substations each transformer would be a unit with a synchronous condenser supplied from a tertiary winding.

14. The studies which have been made and the tentative designs which have been built up serve to establish confidence in the conclusion that 220-kv. transmission is immediately feasible as a commercial proposition.

15. It is hoped that public presentation of these 220-kv. studies may serve in some measure to facilitate the working out of this advance in the transmission art, and that in particular it may promote interchange of ideas, bring out constructive criticism and stimulate needed investigations.

The author wishes to offer acknowledgment and express appreciation of the assistance of his associates and of various engineers and manufacturers whose ideas have been sought and freely used in the preparation of this paper.

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(*Subject to final revision for the Transactions.*)

THE DIELECTRIC FIELD IN AN ELECTRIC POWER CABLE

BY R. W. ATKINSON

ABSTRACT OF PAPER

The data given pertain particularly to the field of three-conductor three-phase cables when supplied with three-phase voltage and are primarily the solution by physical measurements of some of the geometric problems of the three-conductor three-phase cable.

Data are given so that it is possible, from electrical measurements on three-conductor cable, to determine certain specific quantities as permittivity, resistivity, etc. of the dielectric of three-conductor cable in the same way as can readily be done for single-conductor cables from goemetric considerations.

Also, there is shown the potential and stress distribution in three-conductor cable. The most extensive data are based on measurements made with electrodes in an electrically conducting liquid, thus simulating a homogeneous dielectric. Also exploring electrodes were built into some actual three-conductor cable, and measurements were made when three-phase voltage was supplied to the conductors.

IN the case of single-conductor cable, by means of simple mathematical calculation it is readily possible to calculate from the fundamental data, the unit quantities of the dielectric, such as permittivity, thermal or electrical resistivity, the corresponding properties of the cable itself. Also the voltage gradient at the conductor surface or elsewhere in the insulation may easily be determined in terms of the applied voltage and the cable dimensions, or the unit quantities may be determined from measurement upon cables.

Very few corresponding data from three-conductor cable are available. The reason for this is the difficulty of the mathematical work required for this solution and also the complicated form of those results which have been obtained. By means of electrical measurements in a tank of conducting liquid containing electrodes representing the conductors and sheath of a cable a solution is obtained of many of the problems of the three-conductor cable. Also there are reported the results of a few measurements of voltage gradients and of potentials in an actual three-conductor cable.

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A great many data are available regarding the effect of stranding of single-conductor cable upon the gradient and the dielectric strength. We have added somewhat to the data now available on voltage gradient. For various reasons, the practical effect on dielectric strength of the increase of gradient due to stranding is not in proportion to that increase. Two reasons probably predominate; the change in gradient affects only a very small thickness of dielectric; it probably usually occurs that a better mechanical construction results when paper wrappings are applied to a stranded then to a solid conductor. Further data regarding this matter are of very considerable importance.

It is intended to leave most of the application of this data for presentation at a later time, though some of the directions in which it is useful will be pointed out briefly. It is important to distinguish from the beginning between two distinct uses for the data given. First there is the correlation of the capacitance of the cable with the permittivity of the dielectric, the resistance of the cable with the resistivity of the dielectric, etc. Second, there is the determination of voltage gradient. Concerning the first there is a very definite and immediate application. The field of application of the second is much less definite though actually far more extended. The distribution of the voltage gradient in various parts of a cable is one of the several fundamental considerations governing the voltage rating of the cable.

Measurements of stresses and capacities, both three-phase and single-phase, were begun in the laboratory of the Pittsburgh factory of the company with which the writer is associated, in 1913, under the direction of C. W. Davis. At this time were begun the experiments with a tank of liquid, or solid electrolyte similar to that hereinafter described and the results obtained were substantially in accordance with the results herein published. Later experiments were made at Perth Amboy in 1917 and again in the spring of 1919 by the writer. In the successive series of tests some of the earlier measurements were repeated and the field of study was extended, and apparatus was devised which would permit of a still more accurate measurement of the stresses than those obtained in 1913. This paper deals largely with the actual measurements made in the last two series of tests, though a brief summary of part of the earliest series is added.

DETERMINATION OF CAPACITY RELATIONS

The determination of capacity relations will first be described. The experimental work consisted in the measurement of resistance between electrodes placed in a tank of electrolyte with the electrodes so arranged that they occupied the same relative position to each other as do the separate metallic parts of a three-conductor cable.

The terms conductors and sheath will be applied to the electrodes representing them and the terms conductor and belt insulation to that part of the electrolyte occupying the position that the conductor and belt insulation would occupy in a cable. Also the terms "filler" or "filler space" will be applied to the part of the section corresponding to that part of the cable section usually occupied by jute or paper "filler." The term cable will be applied to the complete set of electrodes and electrolyte, in any one arrangement.

The capacity relations were determined in the following manner. The conductors and sheath were arranged in their relative positions in a wooden tub containing fairly high resistance water. Measurements were made of the resistance between electrodes when they were connected in various ways. The following were the connections used.

1. One conductor *vs.* another conductor. (Sheath and third conductor free).
2. One conductor *vs.* two conductors. (Sheath free).
3. One conductor *vs.* sheath. (Other conductor free).
4. One conductor *vs.* one conductor and sheath. (Third conductor free).
5. One conductor *vs.* the other two conductors and sheath.
6. Two conductors *vs.* sheath. (Third conductor free).
7. Two conductors *vs.* sheath and third conductor.
8. All conductors *vs.* sheath.

One of the same conductors was then placed in the center of the same sheath and a reading taken of resistance between conductor and sheath thus forming the equivalent of a single conductor cable. The ratio of the resistances for the three-conductor connections to the resistance of the single-conductor to sheath gave the ratio of capacities for the three-conductor connections as compared to the capacity of a single-conductor cable having the same size conductor and sheath. The single-conductor capacity can easily be calculated. The matter may be explained in another manner. The measurement with concentric tubes furnishes data for ready calculation of the resistivity of the electrolyte. The three-conductor measurements thus are made with "dielectric" of known resistivity and conductors of known dimensions.

The above measurements were made with various proportions of belt to conductor insulation and with various ratios of conductor to sheath diameter.

The resistance measurements were made using single-phase 60-cycle current, by measuring the applied voltage and the energy consumed in the resistance of the electrolyte. For the latter measurement there was used the wattmeter connection of a Rowland dynamometer, the connection being such that the resistance of the fixed coils was included in the measurements. Approximately two volts from an auto-transformer

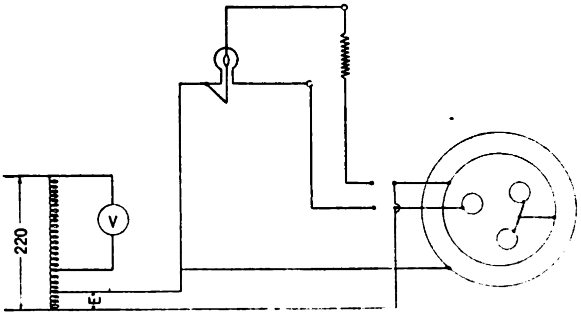

Fig. 1—Wiring Diagram for Determining Capacity Relations

was applied to the tubes, and watt readings were taken for the various connections, from which the effective resistance between the electrodes could be calculated. The dynamometer was calibrated by substituting a variable known resistance for the electrolyte.

The bottom of the tub was covered with a layer of paraffine which prevented end effect due to possible conduction in the water-soaked wooden bottom, and also served as a flat level bottom on which to rest the tubes.

To check the general accuracy of the method and the applicability of the results, a large number of measurements were made with concentric tubes. Resistance measurements were made between many combinations of pairs of different sizes. Also after a measurement was made between such a pair of rings, a third one was placed between the two and concentric with them and measurements repeated. By this means it was shown that the resistances obeyed the theoretical law.

These measurements showed that end effect actually had been eliminated by the initial arrangement.

Another disturbing factor was detected and eliminated through the agency of these tests. The tubes or rings seemed to have a high surface resistance possibly due to polarization.

TABLE I.

Sheath Diam.	Cond. Diam.	Ratio thickness belt insulation Ratio thickness conductor insulation
15.4 in.	3.62 in.	0.
"	"	0.25
"	"	1.0
15.4	2.50	0.
"	"	0.25
"	"	1.0
15.4	1.90	0.
"	"	0.25
"	"	1.0
11.8	2.5	0.
"	"	0.25
"	"	1.0
11.8	1.9	0.
"	"	0.25
"	"	1.0
9.9	2.5	0.
"	"	0.25
"	"	1.0
9.9	1.9	0.
"	"	0.25
"	"	1.0

Water of fairly low resistivity was being used (a very weak saline solution). The resistance was increased largely by the use of distilled water mixed with a very small amount of tap water. This however only partly removed the difficulty, as the surface resistance, the relatively smaller, was larger absolutely, and large enough to cause the results to be slightly in error. It was found that if the tubes were thoroughly polished with fine sandpaper or emery cloth at sufficiently short intervals this resistance could be entirely eliminated. In measurements of stress, described later, even a much lower surface resistance would have been of importance, but careful tests showed it was possible to entirely free the results from this type of error. Attempts were made to use some rings made of galvanized iron, but this material did not give satisfactory results and was abandoned.

Measurements were made with the sizes and arrangements of electrodes shown in Table I.

All tubes were of copper and 8½ in. high. The readings for different connections for any one cable checked the relations given by Russell within 2 per cent.

These relations are as follows;

TABLE II.

(1) Capacity between 1 and 2 $= (a - b)$
(2) " " 1 and 2, 3 $= 2/3\ (a - b)$
(3) " " 1 and S (2 and 3 insulation) $= \dfrac{(a - b)(a + 2b)}{a + b}$
(4) " " 1 and S, 2 (S insulated) $= \dfrac{(a - b)(a + b)}{a}$
(5) " " 1 and S, 2, 3 $= a$
(6) " " S and 1, 2 (3 insulated) $= \dfrac{(a - b)(a + 2b)}{a}$
(7) " " 1, S, and 2, 3 $= 2\ (a + b)$
(8) " " 1, 2, 3, and S $= 3\ (a + 2b)$

With each cable, actual measurements were made of all the 8 combinations though the tests on No. 1 and No. 5 were made with the greatest care. From these, the values of *a* and *b* were calculated and following this, the values of the other six combinations. Check with measurements was made as indicated above.

APPLICATION OF DATA OF CAPACITANCE AND CHARGING CURRENT

The data of these measurements are shown only in the final form, Fig. 2. Specifically, Fig. 2 gives the charging current of different sizs of cable within the range of present practise. The values are based on a frequency of 60 cycles and a specific inductive capacity of 3.27, the latter being a somewhat arbitrary figure but actually about the normal value for impregnated paper. By the use of constants given below, the chart may be used for determination from the unit quantities, of the various other properties of a three-conductor cable.

To find microfarads per mile multiply values taken from curves by 0.014.

To find insulation resistance of any cable in megohm-miles divide the number of megohms resistivity (cm. unit) of the dielectric by the value obtained from the curve Fig. 2 and multiply by 2.06×10^{-5}.

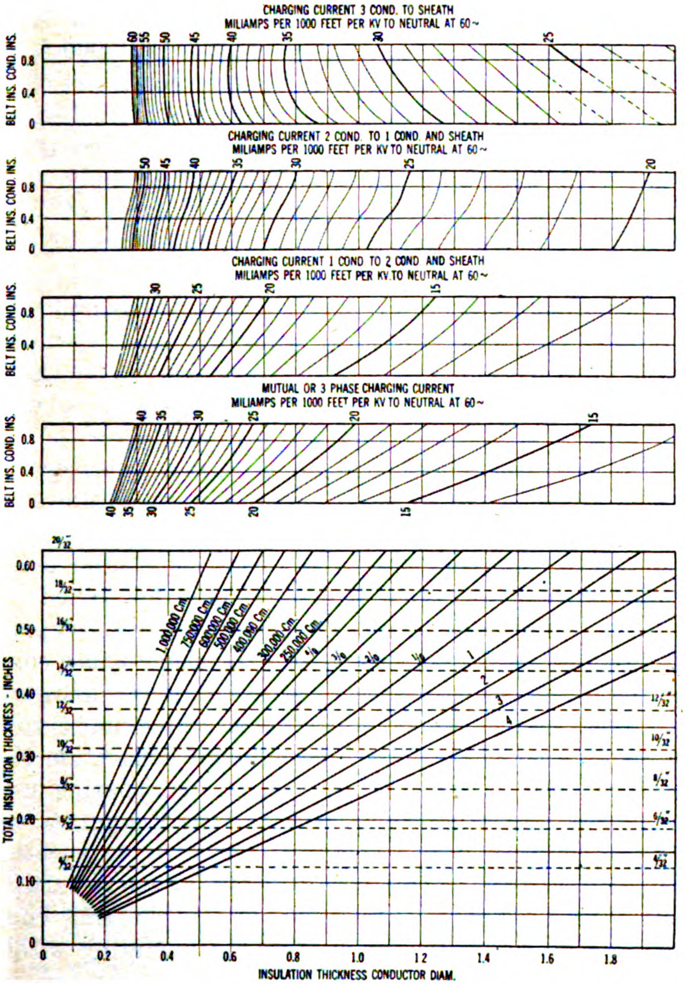

FIG. 2—CHARGING CURRENTS FOR ROUND THREE-CONDUCTOR CABLES BASED ON SPECIFIC INDUCTIVE CAPACITY OF 3.27 AND A FREQUENCY OF 60 CYCLES

To find the temperature rise across the insulation due to one watt per foot of copper I^2R in a 3-conductor cable, divide 0.1097 by the charging current given for three conductors to ground and multiply by the thermal resistivity in watt-cm. units. (This is of the order of 500 to 1000 for most insulating materials.)

The number of milamperes per kv. to neutral per 1000 ft. is also equal to the number of volt amperes per 1000 ft. with one kilovolt of three-phase voltage between conductors. This forms a very convenient basis for comparison of dielectric loss data on cables of different size conductors and different thickness of insulation and with three phase voltage supply. When the power factor and specific inductive capacity of any insulating material are found by tests on one or more cables, the three phase losses in kw. per 1000 ft. on any other cable with that insulating material may be determined by multiplying the voltamperes per 1000 ft. as obtained from the chart, by the power factor, by the ratio of the specific inductive capacity to 3.27, and by the square of the number of kilovolts between conductors.

It will be observed that though all the capacity measurements indicated are with single-phase current supply, data are given for three-phase charging current. There is a very simple theoretical relation between the three-phase connection and the single-phase connection No. 1 but we have not relied solely upon that. The measurements may be considered as supplying information as to charging current of the single-phase connections only. By measurements on many cables it is known that the charging current per conductor with three-phase voltage is the same as that for single-phase voltage, connection No. 1, when the voltage from conductor to sheath is the same in each case. (In case of connection No. 1 the third conductor is at sheath potential, whether actually connected to sheath, or free). This is the theoretical relation said above to exist.

Sometimes it is important to know the charging current which may flow in the case of a system operating with ungrounded neutral, when one of the lines becomes grounded. The value of the current is of importance for various reasons external to the cable itself. Also on account of large increase in the kilovolt-amperes of the charging current there will be at least a proportionate increase of dielectric losses. This particular data are calculated from the other data given by the use of the same method Russell gives for calculating the relationship of the various single-phase capacities. The data follows:

Let C_5 and C_8 represent respectively the single-phase charging currents per kv. for one conductor against the other two and sheath, and for three conductors against sheath. For normal three-phase operation then, the charging current per kv. to ground on each conductor is equal to $1.5\,C_5 - 0.167\,C_8$. With a grounded conductor the charging current on each of the free conductors per kv. is equal to $\sqrt{0.752\,C_5^2 + 0.027 C_8^2}$, which, for practical purposes is identical with $0.91\,C_5$. The charging currents per kv. on the grounded conductor and on the sheath, are, respectively, equal to $0.0866\,C_5 - 0.288\,C_8$ and $0.577\,C_8$. With a given operating voltage E between conductors, the charging current values are therefore as follows:

For each conductor on normal three-phase operation .... $E(0.866 C_5 - 0.096 C_8)$

For each free conductor when one of the conductors is grounded .... $0.91 E C_5$

For the grounded conductor .... $E(0.866 C_5 - 0.288 C_8)$

For the sheath when one of the conductors is grounded .... $0.577 E C_8$

The total volt-amperes due to the charging current will be, on normal operation $\sqrt{3} EI$, which is equal to

$$E^2\,(1.5 C_5 - 0.167 C_8)$$

and when one conductor is grounded

$$E^2 (1.5 C_5 + 0.167 C_8)$$

Let us take as an example a three-conductor cable with 4/0 conductors having 6/32 in. insulation on each conductor and 6/32 in. on the belt, and at, say, an operating voltage of 11 kv.

$C_5 =$ 0.0202 amperes per kv. per 1000 ft.
$C_8 =$ 0.0365 amperes per kv. per 1000 ft.

The charging current with ordinary operation is, therefore, 0.154 amperes.

With one of the phases grounded, the charging current for each free conductor is 0.203 amperes, for the grounded conductor 0.077 amperes, and for the sheath 0.231 amperes.

The total volt-amperes for the case where the neutral is grounded will be 2930, and for the case where one of the conductors is grounded 4400. On the basis of the same power factor, the dielectric loss, as well as the volt-amperes of the charging current, in the second case, will be 50 per cent higher than in the first.

EXPLANATION OF NATURE OF FIELD WITH THREE PHASE VOLTAGE SUPPLY

Fig. 4 is presented largely to illustrate the general nature of the field in the three-conductor cable upon which is impressed three-phase voltage. On one part of the curve are shown isophase lines. Any of these lines is the locus of the point which passes through zero voltage (above neutral) at some one instant of time. Another group of lines are called lines of equal maximum potential. This group should not be confused with the equipotential lines which may be drawn to represent instantaneous values of an alternating or a polyphase field. Any one of these lines is the locus of the point which reaches a certain value of maximum voltage above ground, the time not being specified. The two sets of lines completely specify the field in the cable.

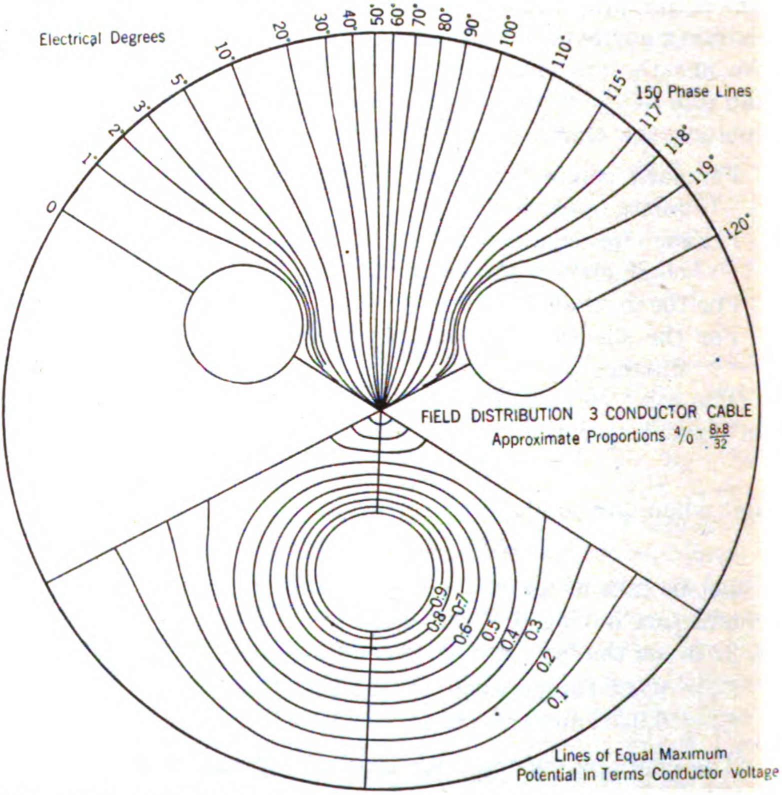

FIG. 4—LINES OF ISOPHASE AND LINES OF EQUAL MAXIMUM POTENTIAL

It is not intended here to describe the method used for determining these data as it is not dissimilar to that fully described for determination of other data.

A conception of the field may be gained by referring first to the lines of equal phase. At the first instant of time, zero degrees on the scale, the conductor *A* and all points along the center line from conductor center through cable center pass through zero voltage. After an interval of time represented by one electrical degree, the locus of the points of zero potential has moved somewhat to the right. It will be noted that near the sheath there is a large movement, a lesser one near the conductor surface and near the center the movement is too small to warrant plotting the line to the cable center. It will be observed that the change of phase is much more rapid (that is, a given distance corresponds to much more phase change) as the line through cable center and bisecting the center line of conductors, is approached. At the center of the cable the phase lines rotate at a uniform angular velocity.

The lines of equal voltage begin at very low voltages as circular in form, near the cable center. At very low voltages this is greatly changed and later these lines approach a circular form around the conductor. Note that wideness of spacing does not indicate low stress, especially near the position midway between two conductors. From the latter series of lines alone it would be concluded that the stress at this point is low. Actually, however, points here only a short distance apart reach their maximum potential above ground at a period of time so different that the voltage gradient at this part of the section actually is very high.

From these data may be found for any point in the cross section, the potential above ground and the phase relation of this voltage. If the voltage to be found for any two points at a short distance from each other, the stress in the insulation may be determined. However, data of a sufficient degree of accuracy to be of any value at all could be obtained by this means only with apparatus and methods of very great precision. These data were obtained in a different manner now to be described. Incidentally it may be remarked that the potential data shown in Fig. 4 might readily be calculated from the stress data recorded later.

STRESSES AS MEASURED WITH ELECTROLYTE TANK

The stresses in the three-phase field were measured in the following manner: An exploring device was made up as shown in Fig. 5. Two steel rods about 1/16 in. in diameter and 8½ in. long were fitted into small hard rubber blocks so as to form a frame. Half way between the steel rods and with their plane perpendicular to the plane of the rods, two No. 26 bronze wires were held taut. These bronze wires, which were approximately 0.25 in. apart, served as the potential electrodes. The potential between the wires divided by the distance apart is quite accurately equal to the stress at the point half way between them.

The whole exploring device was freely suspended from the tracing point of a pantograph, Fig. 6, the drawing point of which indicated upon a representative drawing, the position of the electrodes in the tank.

Fastened to the exploring device above the point where it was suspended was fixed a small pointer which indicated upon a circular scale the plane of the electrodes. The rigging of the pantograph, Fig. 6, was so arranged that any line on the circular scale always maintained a fixed angle with any line upon the representative drawing.

In order to measure voltage between these points when they are in the field between the three conductors, upon which is impressed three-phase voltage, it is necessary to measure the magnitude and phase displacement with respect to a fixed voltage and to do so without dis-

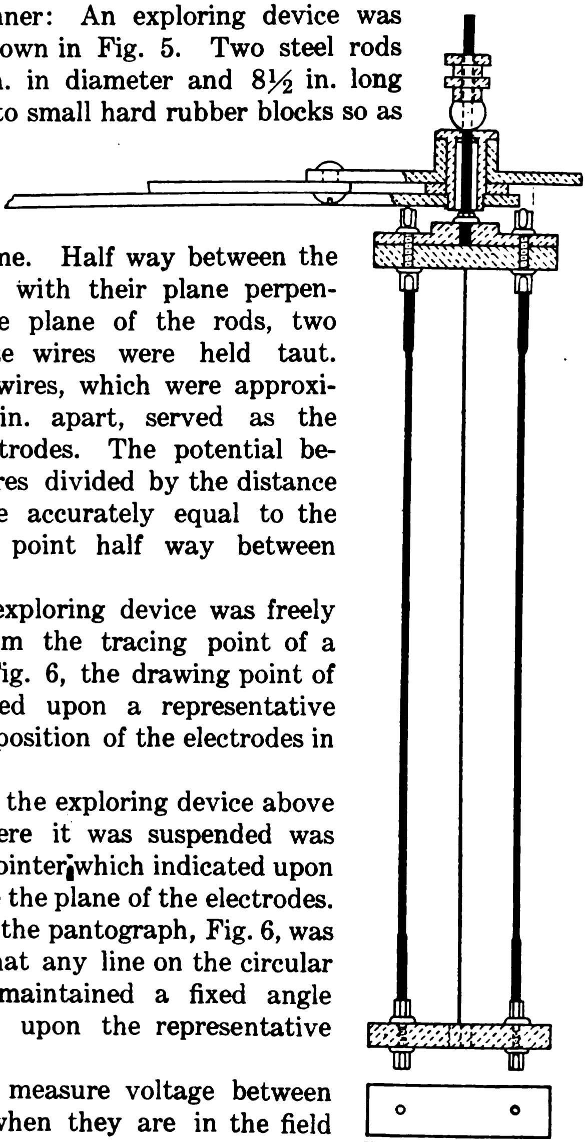

FIG. 5—EXPLORING DEVICE

tortion of the electrical field by the measuring current. The second requirement demands that a null method be used or that the instrument for measuring the voltage be of sufficient sensitivity so that the current which it takes will distort the field by a negligible or a very small and known amount. It will be seen below that the latter arrangement has been used with very satisfactory results. To secure the correct measurement of the voltage regardless of its phase and to measure the displacement, it was first proposed to make use of a phase shifting transformer, but the method to be described proved actually simpler in operation and fully as accurate in results.

The potential across the electrodes was measured by means of a Rowland electro dynamometer the field of which was separately excited with fifty amperes as shown in Fig. 7. The connections were so arranged that it was possible to obtain currents in the field circuit that were equal and ninety degrees out of phase with each other by merely throwing a switch (No. 1). These currents were obtained by taking taps from a star-connected three-phase transformer, one side of the switch being connected across one leg of the transformer winding, the other being connected across approximately 58 per cent of winding of the other two legs. The neutral of the transformer was grounded. The potential circuit contained 40,000 ohms non-inductive series resistance.

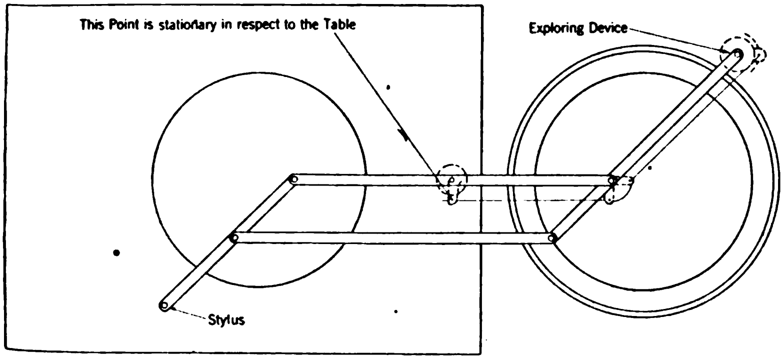

FIG. 6—PANTOGRAPH

The reactances of the fixed coil and the auto-transformer were compensated by a capacity of 16 microfarads shunted across a variable resistance. The compensation was accomplished in the following manner: A voltage in phase with the voltage across one side of the main field switch was impressed on the moving coil circuit. When the switch No. 1 was thrown on that side, the field current was approximately in phase with the current in the potential circuit and a large deflection resulted. With the switch No. 1 thrown in the opposite direction, the field current was nearly 90 degrees out of phase and a very small deflection resulted. The resistance which shunted the condensers was then varied until this deflection was zero.

To insure that the voltages on the two sides of the switch are at the proper 90 degree relation with each other, the circuits were then interchanged so that voltage from the other side of No. 1 switch was required to produce zero deflection. It was found that the phase relation was correct within ½ per cent.

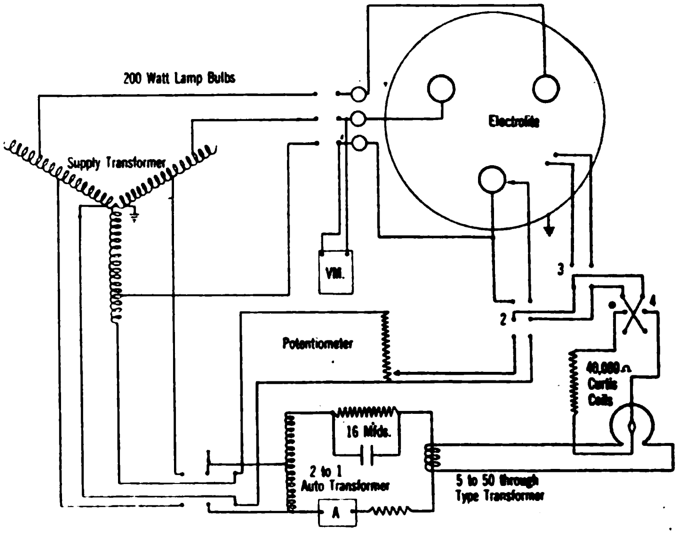

Fig. 7—Wiring Diagram of Connections for Stress Measurements

The procedure of the stress measurements was then as follows:

An accurate template was made of thin Bakelite fibre so that the conductors and sheath always maintained the same relative position.

A large circular piece of plate glass was placed in the bottom of the electrolyte tub and was then leveled by means of a spirit level. The electrodes were then placed in the tub and held in their positions by the template. The tub was then filled with water to within a half inch of the top of the electrodes.

Three-phase voltage of approximately 50 volts to neutral was then applied to the three conductors and the exploring device suspended in the water. The measurements were made in the field surrounding the conductor *A* whose voltage was in phase with the field current when the field switch No. 1 was placed on the left hand side.

A full size drawing was then made which exactly corresponded to the template and various circles and lines were drawn upon it as shown on Fig. 8 the intersections of this line indicating the points at which it was desired to measure the stress.

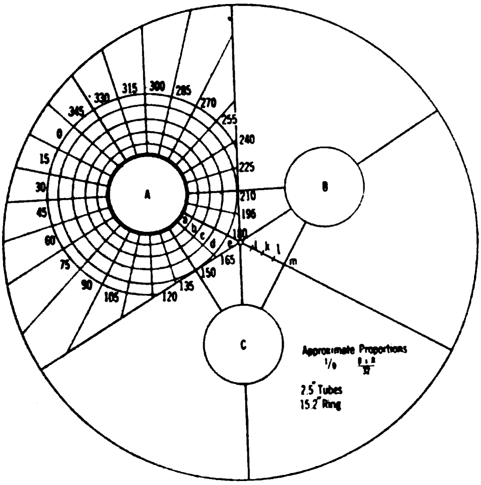

FIG. 8—CROSS-SECTION OF CABLE SHOWING RELATIVE POSITIONS OF CONDUCTOR AND SHEATH AND POINTS AT WHICH STRESSES WERE MEASURED

The drawing was then lined up as follows:

The exploring device was hung somewhere near the center of the cable. The two electrode-wires were short-circuited and the voltage between these and the sheath was measured by means of the dynamometer. At exactly the center of the cable the voltage to sheath is zero. The electrodes were moved about until the dynamometer indicated zero with the field switch on either side. The center of the representative drawing was then placed exactly under the drawing stylus and fixed to the board with a thumb tack.

The exploring device was then placed between the two conductors *B* and *C*. At a point exactly half way between these conductors, the potential to sheath is in phase with the voltage of conductor *A* to ground. The switch was then thrown on the side that is out of phase and the exploring device moved until the deflection was zero. The drawing was then swung about with its center as an axis until the line half way between conductors *B* and *C* was under the stylus. The drawing should then be exactly lined up with the tank. Checks were made by placing the exploring device near one of the conductors and visually comparing its position relative to the conductor with the position of the stylus to the conductor on the drawing.

The circular scale for measuring the direction of the plane of the electrodes was then adjusted by measuring stress along the 180-degree line. The stresses along this line are in phase with the voltage of conductor *A*. Normal to this line there is a large phase change. With the field current out of phase with the potential of conductor *A* the dynamometer will read zero only when the plane of the exploring electrodes coincides with the 180-degree line. With the stylus on the 180-degree line near conductor *A* the exploring device was turned about its axis until the deflection became zero. The zero on the circular scale is then adjusted to coincide with the pointer. Check was made to insure that the actual position was as above stated.

Readings were then taken by placing the stylus at the intersections of the radial lines and the circles shown in Fig. 8. Readings were also taken at the other points indicated. All readings were taken with the plane of the exploring electrodes radial to the conductor except along the 180-degree line where the stresses were also measured normal to the line.

Stresses close to the conductor were found by measuring between the conductor and a No. 40 wire fastened by hard rubber cleats 0.125 in. from the conductor. This conductor could be revolved in the template and the stresses on all sides of the conductor could be accurately compared.

To take a reading, the stylus was placed on a point on the drawing at which it was desired to measure the stress. The exploring device was rotated until its electrodes were radial to the conductor. Readings were taken of voltage and dynamometer deflection with the main field switch first on one side and then on the other. This gives both components of the stress as compared to the voltage to neutral of conductor *A*. From these readings the stress and angle could easily be calculated.

Voltage was read across the points indicated on Fig. 7. This voltage was frequently compared with the voltage directly on the conductors. The three-phase field would have been slightly distorted had it been attempted to keep the voltmeter connected to the conductor while making stress measurements, due to the slight additional drop across the series lamp bulbs.

Calibration of the instrument was made by means of a potentiometer connected as shown in Fig. 7. A deflection of the dynamometer of 0.88 divisions per volt was obtained with 40,000 ohms series resistance and 50 amperes field current. All results were placed on a common basis of field current and conductor voltage.

The deflections along the 180-degree line were plotted and the average of this curve between the conductor and center of cable was found. The average voltage between the conductor and center of cable was the voltage on the conductor divided by the distance. The average deflection divided by the calibration constant and by the distance between the exploring electrodes must exactly check the average voltage. From this relation it is possible to find the exact distance between electrodes.

We have mentioned the possibility of field distortion due to the current taken by the apparatus used for measuring the potential difference of exploring electrodes. The effect of this upon the measurements described above was investigated in the following manner. With the exploring electrodes maintained in a given electric field in the tank, the resistance in the metering circuit was varied through a wide range. The reciprocals of the deflections were plotted as ordinates against the external series resistance as abscissas. The resultant "curve" was a straight line cutting the axis at a negative value. This value is equal to the effective resistance between the electrodes If this resistance be added to the external resistance in determining the calibration constant, we fully correct for small distortion which does occur, for it follows from the above that the same voltage is obtained regardless of the series resistance and therefore the value is the same as for infinite resistance, or zero current and distortion.

The calibration of the electrode fastened to the tube was found by measuring the stress in a single-conductor concentric field. The stress can here be quite accurately calculated and the distance between the No. 40 wire and the tube was found from the relation that the stress at a point half way between the wire and the conductor must equal the deflection divided by the calibration constant of the instrument divided by the distance between the wire and conductor. The internal resistance between this electrode and the conductor was found in the same way as for the other. The calibration constant to be used for any given condition is that given above, which applies to 40,000 ohms total resistance, divided by the ratio of the actual total resistance of the potential circuit (including internal resistance between electrodes) to 40,000. This ratio does not exceed 1.02 or 1.03.

All deflections were put on a common basis by dividing by the average deflection between the conductor and center of cable along the 180-degree line, thus giving the stresses in terms of the average along the 180-degree line from conductor to center of cable.

The two components of the stresses were added at right angles and the angles by which the stresses lead the voltage of conductor *A* to ground were calculated.

The values were plotted in Figs. 9 to 18 inclusive which will be described in detail below.

The field between the conductor and the sheath was next investigated. The electrodes were placed on the shortest line between conductor and sheath, and the deflection read. The other two tubes were then removed without disturbing the position of the remaining electrode or its voltage to ground. The deflection was not changed by the removal of the other conductors. Other spacings and sizes of tubes were used but never did the removal of the two tubes change the amount of the deflection. From this, we can draw the conclusion that the field on the shortest line between the conductor and sheath is a single-phase field and is independent of the presence of the other two conductors.

Determination was then made of the effect of the amount of belt upon the stresses on the inside of the cable. Readings were taken with the tubes so arranged as to simulate a cable with equal belt and conductor insulation. Then without changing the position of the conductors, the sheath was replaced by a smaller one. This new ring was even smaller than one that would correspond to the sheath of an unbelted cable. Most of the readings were then repeated. The change in sheaths produced practically no change in stress within the portion of the field bounded by the three lines joining centers of conductors.

DESCRIPTION OF FIGS. 9 TO 16

Fig. 9 shows the stresses along the line joining the center of conductor *A* and the center of cable in terms of the average stress between the conductor and the center. This average represents the total voltage of conductor *A* divided by the distance between the conductor and center of cable.

In all the following curves, as well as most of the subsequent discussion, stresses are given in terms of this same unit. For a round conductor, this distance between conductor and center is equal to the conductor insulation (half the distance between surfaces of conductors) plus 0.154 times the conductor diameter.

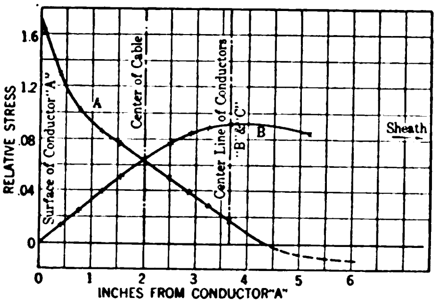

FIG. 9—STRESSES ALONG 180 DEGREE LINE OF FIG. 8 IN TERMS OF AVERAGE BETWEEN CONDUCTOR AND CENTER OF CABLE (SMALL TUBES)

Curve A—Stresses in direction of 180 degree line
Curve B—Stresses normal to 180 degree line

Curve *B* shows the stress normal to the line of centers of conductor *A* and cable. Here the maximum stress occurs near the line joining the centers of conductors *B* and *C*.

Fig. 10 shows the stresses around the circle *a* which is 1/16 in. away from the conductor. All stresses were measured radial to the conductor. It will be noticed that the maximum stress occurs on the line which passes through the center of the cable though there is very little difference along the arc inclosed by the center lines of conductors.

Another maximum occurs at the outside of the conductor on the shortest line between the conductor and sheath. This maximum is dependent upon the total thickness of insulation including conductor and belt.

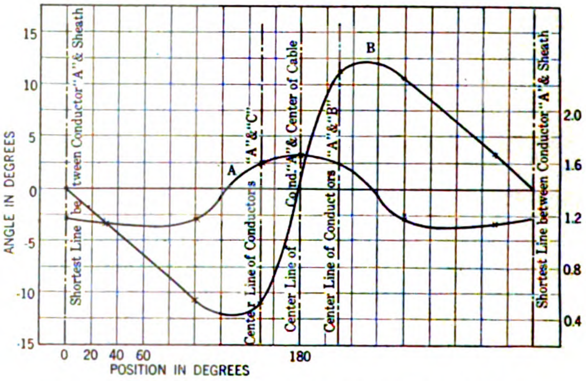

Fig. 10—Stresses on Circle (a) of Fig. 8

Curve A—Stresses in terms average stress between conductor and center of cable along 180 degree line (Fig. 8)

Curve B—Angle by which stress leads voltage of conductor A to neutral

Right hand ordinate—relative stress

Figs. 11, 12, 13 and 14 show the stresses on the various other circles shown. It will be noted that as the distance between the conductor and circle increases that the point of maximum stress moves toward the line joining centers of conductors. Also the point of maximum phase difference moves farther past the line joining centers of conductors.

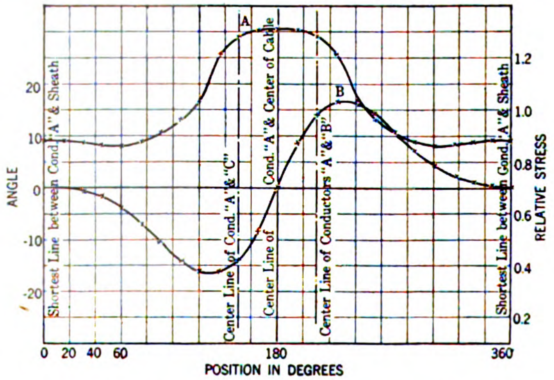

Fig. 11—Stresses on Circle (b) of Fig. 8

Curve A—Stresses in terms average stress between conductor and center of cable along 180 degree line (Fig. 8)

Curve B—Angle by which stress leads voltage of conductor A to neutral

Fig. 15 shows the stresses on the outside of the conductor along the shortest line from the conductor to sheath. This is a single-phase field and the maximum stress can be calculated by a formula given by Russell as shown below. The value obtained from the curve checks within 2 per cent the calculated value.

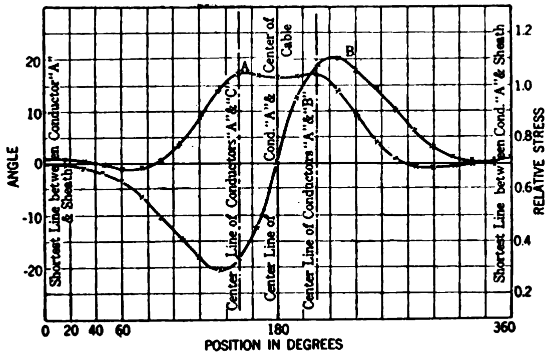

FIG. 12—STRESS ALONG CIRCLE (C) OF FIG. 8

Curve A—Stresses in terms average stress between conductor and center of cable along 180 degree line (Fig. 8)
Curve B—Angle by which stress leads voltage of conductor A to neutral

The middle curve of Fig. 16 is a graph of the common formula showing relation between maximum and average stress of a single conductor cable. This is

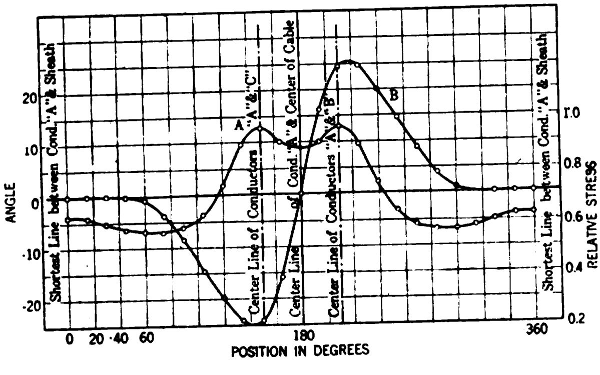

FIG. 13—STRESS ALONG CIRCLE (D) OF FIG. 8

Curve A—Stresses in terms average stress between conductor and center of cable along 180 degree line (Fig. 8)
Curve B—Angle by which stress leads voltage of conductor A to neutral

$$\frac{\text{maximum stress}}{\text{average stress}} = \frac{R - r}{r \ln R/r}$$

r being the radius of the conductor, R the radius of the insulation over the conductor (in being mutual logarithm).

Russell gives a formula for the maximum stress between eccentric cylinders. Since we have found that this maximum is unaffected by the presence of the other two conductors of a cable, we may expect our values to check a solution of Russell's formula, and as stated, have found they do so. The lowest curve in this figure is a solution of the somewhat long formula.

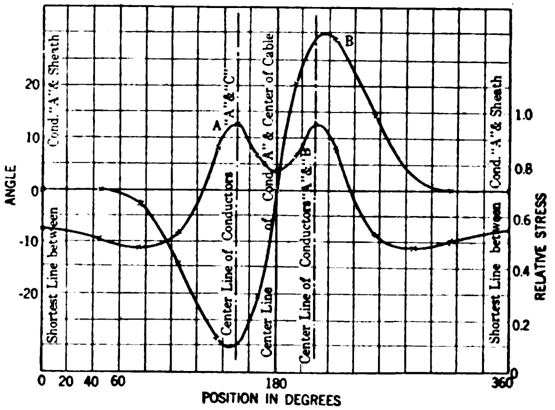

FIG. 14—STRESS ALONG CIRCLE (E) OF FIG. 8

Curve A—Stresses in terms average stress between conductor and center of cable along 180 degree line (Fig. 8)

Curve B—Angle by which stress leads voltage of conductor A to neutral

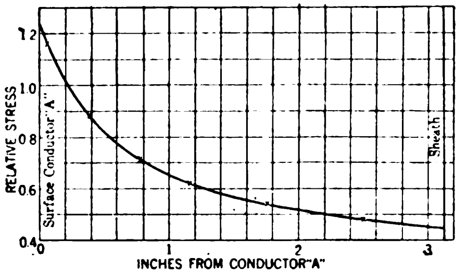

FIG. 15—STRESSES ALONG 0 DEGREE (FIG. 8) IN TERMS AVERAGE BETWEEN CONDUCTOR AND CENTER OF CABLE ALONG 180 DEGREE LINE (SMALL TUBE)

There are several variables in the formula and an exact solution for all conditions would require a series of curves. However, the use of the coordinates taken has enabled us to plot a single curve which is correct for any point within about one per cent.

The upper curve in this figure shows simply the ratio between the stress for single conductor cable and that toward the sheath of a three conductor cable with the same total insulation thickness. These curves are very useful for supplying data outside the range of the experimental values.

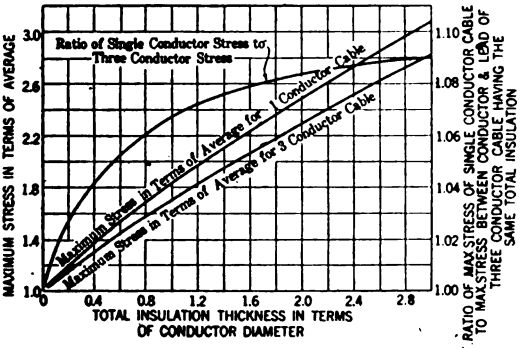

FIG. 16—CURVES SHOWING RELATION BETWEEN STRESS OF THREE-CONDUCTOR CABLE AND STRESS OF SINGLE-CONDUCTOR CABLE AND BETWEEN MAXIMUM AND AVERAGE STRESS OF EACH

Fig. 17, Curve *A*, gives the stresses between the conductors on the line joining their centers. Curve *B* gives the angle by which the stress leads the voltage of conductor *A* to neutral.

The vector diagram of Fig. 18 was obtained by the summation of the stresses along various lines, as will be noted. The arc *A Z B B* was obtained by the addition of potential differences obtained by the integration of stresses along the line joining the centers of the conductors *A* and *B*, Fig. 17.

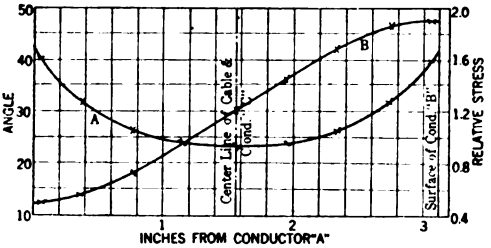

FIG. 17—STRESSES ALONG LINE JOINING CENTERS OF CONDUCTORS IN TERMS OF AVERAGE BETWEEN CONDUCTOR AND CENTER OF CABLE ALONG 180 DEGREE LINE (15.2 IN. RING—2.5 IN. TUBE)

Curve A—Stresses

Curve B—Angle by which stress leads the voltage of conductor A to neutral

We will refer to this simply as the center line of *A* and *B* in the following paragraphs.

The potential at a point along the center line *A B* a short distance from the conductor *A* was determined, being proportional to the area included below the curve *A* and Fig. 17. The vector representing this potential was plotted as the first step of the arc *A Z B B*, Fig. 18, the angle with the horizontal being determined by curve *B* of Fig. 17. Next the voltage between this first point and a second was obtained in the same and a new portion of arc drawn in. (It will be noted that the individual sections of arc are actually drawn as chords). This process was continued for the entire line between conductors *A* and *B*. The voltage from any point to the conductor *A* is represented in magnitude and direction by the line joining it to the point *A*.

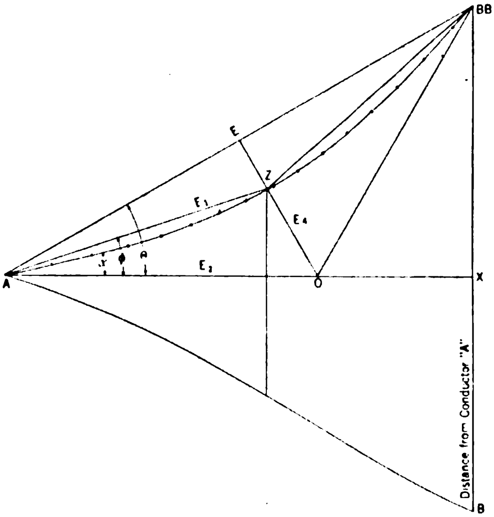

FIG. 18—VECTOR DIAGRAM OBTAINED BY SUMMATION OF STRESSES ALONG LINE JOINING CENTERS OF CONDUCTORS

The vector represented by any of the lines drawn from *A* and terminating on the arc *A Z B B* is the difference of voltage between the conductor *A* and some definite point on the center line of *A* and *B* but since both the abscissae and ordinate of the point on the arc are used to represent potential, it is not possible to show on that curve alone, the location of the point on this center line of *A* and *B*. Therefore, the line *A B* is drawn so that if a vertical line is drawn from any point on the arc to the line *A B*, the intercept between *A Y* and *A B* represents the distance from the conductor *A* to the point the potential of which is represented by the chord drawn from *A* to the said point on the arc. Time the distance *B X* represents the distance of the conductor *B* from the conductor *A*, the potential of *B* being represented by *A B B*.

Also the line *W Y* is equal to half the line *B X* and thus the chord *A Z* represents the voltage from conductor *A* to a point on the center line of *A* and *B* and halfway between them.

The line *A O* represents the voltage between conductor *A* and center of cable, or ground. Also the voltage to ground of any other point is represented by a line to the point *O*, thus *B B O* represents the voltage to ground of the conductor *B*, as determined by the measurements of stress given in Fig. 17.

The actual values of these lines was determined by calculation more accurately than could be done by scaling from a small drawing such as Fig. 18. The following data were calculated for determination of the potential at the point midway between conductors *A* and *B* and also for checking accuracy of measurement and to illustrate the conditions of the field along the center line of *A* and *B*.

The value obtained from the mathematical integration of the stress along the line joining the centers of conductors *A* and *B* was found to be 1.72 times the voltage of conductor *A* to ground and at an angle of almost exactly 30 degrees from this voltage, a very satisfactory agreement with the actual value of 1.73 and exactly 30 degrees.

The voltage from conductor *A* to the point midway between conductors *A* and *B* on the line joining their centers in the chord *A Z* and is equal to 0.07 times the voltage of conductor *A* to neutral and is at an angle of 18.6 degrees from this voltage.

The voltage *O Z* is found either from this diagram or by the integration of the stresses along the line joining centers of cable and conductor *A* between the center of the cable and the line joining centers of conductors *B* and *C*. The two values obtained in these ways are 0.325 and 0.355 respectively in terms of voltage of conductor *A* to neutral and at an angle of 60 degrees from that voltage.

Data given thus far have applied to measurements on a single "cable." Similar measurements were taken of stresses with a different size of conductor. A sheath 15.2 in. in diameter was used and 5.82 inch conductors were so placed that the conductor and belt insulation were equal.

Not as many readings were taken for this "cable," Enough were taken however to show that the maximum stress occurred at the conductor on the line towards the center of cable and to determine stresses at the points of maximum importance. Stresses were taken all along the lines joining the center of conductor *A* and center of cable.

In Fig. 19, curves *A* and *B* respectively are shown the stresses along (parallel to) and normal to, the line joining center of conductor and center of cable.

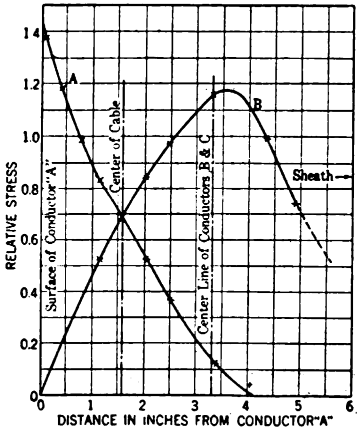

FIG. 19—STRESSES ALONG 180 DEGREE LINE IN TERMS AVERAGE BETWEEN CONDUCTOR AND CENTER OF CABLE (LARGE TUBES)

Curve A—Stress along 180 degree line
Curve B—Stress normal to 180 degree line

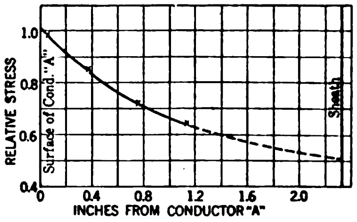

FIG. 20—STRESSES ALONG 0 DEGREE LINE IN TERMS AVERAGE BETWEEN CONDUCTOR AND CENTER OF CABLE ALONG 180 DEGREE LINE FOR 15.2 IN RING AND 3.82 IN. TUBES

Fig. 20 shows the stresses on the shortest line between the conductor and sheath. The maximum of this curve checks within 2.5 per cent the value calculated from Russell's formula as shown in Fig. 16.

USE OF SOLID ELECTROLYTE

In the Pittsburgh experiments of 1913 and 1914 use was made of solid as well as liquid electrolytes. Cable cross sections were prepared of solid electrolytes with cast-in exploring electrodes in which the specific resistivity of the electrolyte occupying the filler space differed from that of the electrolyte representing the conductor and belt insulation. The extreme limit of range of resistivity for the fillers was obtained first, by using solid insulators, and second, by making the fillers of copper.

Also, thermometers were cast into the solid electrolyte so as to note the change in temperature in the cross-section due to the energy loss. One of the solid electrolytes used melted at a relatively high temperature and it is of interest, in passing to note that after three-phase voltage had been applied for a short period, to the tank, filled with such solid electrolyte, all of the electrolyte in the triangle formed by the straight line connecting the centers of the conductors, became molten, thus giving a direct analogy to the over-heating of ordinary 3-core cable as indicated by the characteristic charring of the central filler space, when going to destruction by overheating under three-phase voltages. This phenomenon has been noted by Mr. C. W. Davis as early as 1911.

The characteristic charring of three-core cable was observed by Höchstadter on what we understand was mineral base compound about the same time, although not reported to us until about 1913. It has also been noted on vegetable compound cable by Clark and Shanklin and Louis and Bangs and reported by them in the A. I. E. E. PROCEEDINGS, June 1917, and for some time engineers of operating and manufacturing companies have generally recognized this condition.

The electrolyte experiments of 1913-1914 were part of an investigation into the causes of this type of failure of three-core cable. Supplementing those experiments, covering the same period approximately, a comprehensive set of dielectric loss measurements were made at high and low voltage, and both single-phase and three-phase, on mineral compound and vegetable compound three-core cable. As a result of these experiments, the opinion was reached that the arrangement of conductors and insulation in any ordinary three-core cable is such as to make it inherently weak, the tendency of the center to overheat being increasingly difficult to overcome the higher the operating voltage.

From the users standpoint especially, however, it is very desirable to retain insofar as possible the advantages and economy resulting from having the three conductors under one load sheathing rather than the more costly alternative method of using three single-conductor cables, each separately lead covered, with attendant disadvantages of extra cost due to the increased amount of lead sheathing, and the larger ducts or greater number required.

M. Höchstadter (*London Electrician,* May 19, 1916) has described a way to avoid the disadvantages of the ordinary three-conductor type of cable by converting the cable into what is substantially three single-conductor cables without the attendant disadvantages of disproportionate increase in cost. The conductors may be made sector shaped so that all the space within the single lead sheathing is economically used thus securing a still further gain in economy, since it is obvious that three single-conductor cables separately sheathed could not conveniently be made in sector form and installed in such a way as would permit of their fitting together in order to occupy minimum duct space. The thin metal foil or tape suggested by M. Höchstadter is preferably made of copper thus securing the most effective dissipation of heat.

As part of the characteristic charring of the central portion of a three-conductor cable of normal type is due to internal corona, it is obviously desirable to prevent this as far as possible and what appears to be one of the most effective methods of preventing the occurrence of minute air or gas spaces in the highly stressed portions of cable dielectric is the suggestion of H. W. Fisher in 1911 to apply the previously dried and impregnated tape to the conductor while the conductor itself is submerged under oil. The adoption of this method should make internal corona or ionization of relatively little importance even at the highest voltages likely to be reached for many years to come.

Numerous tests were also made with the electrodes representing the conductors, of different shapes. Certain advantages were found as regards distribution of stress and dielectric loss with a conductor of approximately semi-circular form with slightly rounded corners, and with the approximately flat side toward the sheath. It is conceivable that such a special form would be available in special cases where large conductors are involved, but on account of the constructional difficulties and larger diameter of this form, a modified sector conductor is the most suitable practical alternative for regular use.

Referring again to the use of solid electrolytes, it may be of interest to report the use of such electrolyte in the form of pieces simulating simple forms of solid insulators such as those made of porcelain in use in certain types of cable terminals. By immersing such molded solid electrolyte in liquid electrolyte of higher resistivity there was obtained a direct representation of a porcelain insulator rounded by air, and we were thus enabled to plot the equi-potential line from the point where they leave the surface of the solid electrolyte. This method may be of interest to the designers of porcelain insulators although complicated forms may prove themselves difficult to cast and make self supporting without undue deformation.

Using the same electrolyte method, and following the analogy of heat flow, isothermal lines for various shaped conductors in three conductor cables were plotted in the Pittsburgh experiments of 1913-1914. These show that under the I^2R loss alone the center of a three conductor cable will be lower in temperature than the temperature of the conductors, by a small relative amount. In a cable using three sector shaped conductors, less relative difference was found between the temperature of the center of the cable and the temperature of the conductors than where round conductors were used.

Thornton has explored the field of a three-conductor cable by means of the Hele-Shaw method. He suggested the existence of a triple-frequency field at the center of the cable. In the same series of Pittsburgh experiments data were also secured regarding this point, and also later in measurements with actual cable, at Perth Amboy. All of the measurements made failed to show any such effect as described by Thornton. It is to be expected, however, that measurements carried on with cable at voltages above the ionization point would show pronounced harmonics in the potential wave of stresses at different points.

MEASUREMENT OF STRESSES IN ACTUAL CABLE

For this test a specially constructed cable was used. This cable was in nearly every way like a commercial three-conductor cable with round conductors. Its main differences were that at definite points very thin wires (No. 40 A. W. G.) were laid parallel to the conductor, and that the cable was assembled without "lay".

The conductor consisted of 4/0 stranded conductors with 9/32 in. of paper insulation on each conductor and 5/32 in. on the belt. The separate conductors were made up as follows: Insulation was first applied to a thickness of 1/32 in. Eight

No. 40 wires were then placed at equal intervals around the conductor and parallel to its axis. The same was done after a total insulation thickness of 3/32 in., 6/32 in. and 9/32 in had been applied. This made a total of 32 wires per conductor, or 96 for the cable. Immediately over each set of eight wires two layers of paper were applied by hand. The rest of the insulation was applied in the ordinary manner by machinery.

A three-conductor sector cable with the same size conductors and the same thickness of insulation as the other was also constructed in exactly the same manner. The number of No. 40 wires per layer, however, instead of being eight were only six,—one at each corner of the sector and one half-way between each pair of corners. The total number of wires for each conductor were then 24 and for the cable 72.

The small wires were placed where they were so as to furnish a means of measuring the potentials at these points. Hereafter, then, they will be termed "potential wires." The point at which the potential wires were placed will be termed "potential points." The three conductors of the cable will be designated as I, II, and III. The four layers of potential wires of each conductor, starting at the layer nearest the conductor, will be called, respectively, *A*, *B*, *C* and *D*.

Potential data were obtained, in both the circular and the sector cable, on all four rows. Measurements of voltages on *A* and *B* were taken between each potential wire and its conductor, while values on *C* and *D* were taken between potential wire and sheath. Chiefly because data on *B* and *C* would give relatively little additional information, only results gotten on *A* and *D* are given in this paper.

The problem of measurement of the voltage of the potential wires in the three-conductor cable with three phase voltage applied is quite similar to that encountered in the measurement of potentials and stresses in the electrolyte tank. As before, there is the problem of measuring voltages of various unknown phase relations; this was accomplished in a manner somewhat similar to the one previously described. The current which could be taken without field distortion was much smaller, so small that only a null method seemed available. Also it was desirable to keep the detecting apparatus at ground potential. This explanation, will make clearer the reasons for the methods adopted.

Fig. 21 shows the diagram of the connections used. The current supply was taken from a 40-kw. three-phase transformer, the primary being delta connected. The secondary is star connected and gives a rated voltage of 95. There are taps on each log, of 21 per cent and 42 per cent of the full voltage. The delta primary of the three-phase high-tension transformer, T_1 was connected to the 42 per cent taps, and as the normal rating of this transformer per phase is 440 to 25,000 volts, this gave a voltage per phase of approximately 2300 or a voltage between conductors of about 4000. This voltage was impressed on the cable.

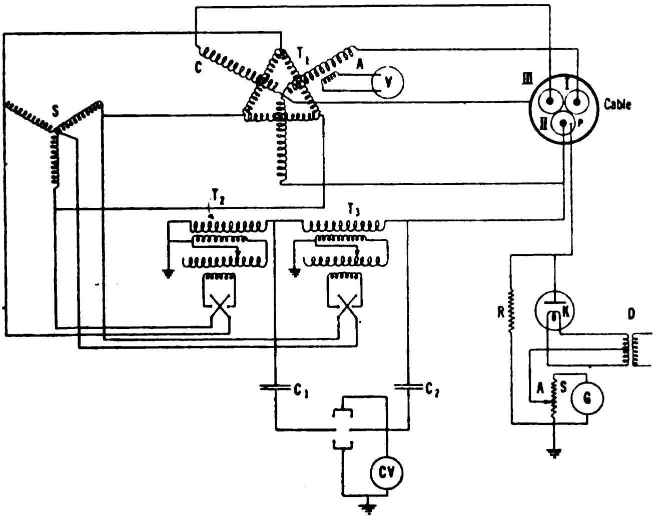

FIG. 21—DIAGRAM OF CONNECTIONS FOR DETERMINATION OF POTENTIAL INSIDE OF CABLE

S—three phase supply
T_1—three phase transformer supplying cable
T_2 and T_3—single phase balancing transformers
V—Voltmeter for T_1
C V—crest voltmeter for T_2 and T_3
C_1 and C_2—condensers used with C V
D—detecting device
K—rectifier (Kenotron)
R—20 megohm resistance shunting K
A S—Ayrton shunt for G
G—d-c. galvanometer
P—potential wire

The balancing voltages were obtained from two single-phase transformers, T_2 and T_3, each equipped with a regulating transformer, thus allowing a selectivity of voltage. The primary of

T_2 was connected to the 21 per cent taps of the two phases of the supply which supplied phase *A* of transformer T_1, thus putting T_2 in phase with phase *A*. The primary of T_3 was connected between the 42 per cent tap of the third supply phase and neutral, thus making the voltage of T_3 90 degrees away from that of T_2. The normal rating of T_2 is 440 to 62,500 volts, with a capacity of 300 kv-a. There are 480 steps in the regulator, so that, with a primary voltage of about 20 volts there are six volts per step. The normal rating of T_3 is 440 to 50,000 volts, with a capacity of 200 kv-a. There are 400 steps in the regulator, so that, with a primary voltage of about 23 there are about seven volts per step. The secondaries of T_2 and T_3 were connected in series, the free end of T_3 being connected to one of the phases or to the neutral of T_1, and the free end of T_2 grounded. T_1 is not grounded at any point, so that the potential above ground of the phase of T_1 or the neutral to which the large transformers T_2 and T_3 are connected, is governed entirely by the voltage of these. This arrangement enables the detecting device to be always near ground potential.

To determine the potential at any point P_2, proceed as follows: Connect the potential wire at *P* to the detecting device. Connect the conductors of the cable to T_1 and the balancing transformers to either the conductor of *P* or to the sheath. Raise the voltage of T_2 and T_3 in the proper direction until the detecting device shows minimum deflection, which indicates that *P* is at ground potential. The voltage produced by T_2 and T_3 will then be accurately the difference of potential, in direction as well as in magnitude, between *P* and its conductor or sheath. This being a null method, the stress distribution, when balance is obtained, is in no wise altered by the measuring apparatus.

The detecting device consisted of a rectifier for which a 100,000-volt, 0.1-ampere kenotron was used in connection with a galvanometer equipped with an Ayrton shunt. The rectifier was shunted by a water resistance of the order of twenty megohms. The rectified current is necessarily unidirectional, and so the proper balance was considered obtained when an increase or decrease in voltage on either T_2 or T_3 increased the deflection. The minimum reading of the galvanometer was not zero, due doubtless mainly to the thermoelectric (Seebeck) effect between the plate and filament of the kenotron, but this did not alter the point of balance.

Voltages were measured as follows: The voltage of T_1 was measured by a voltmeter connected to a tertiary coil of the transformer. The voltages of T_2, and of the combination of T_2 and T_3, were measured by means of a crest voltmeter. By separate measurement the voltage per step of the regulator of T_3 was found to be quite uniform, and its value determined. The voltage of T_3 was therefore calculated from the number of steps on its regulator. Thus, the actual potential difference, as well as its two components, was accurately measured.

ACCURACY CHECKS ON MEASUREMENTS ON ACTUAL CABLE

To determine what error, if any, was due to end effect, the connector of the rectifier was brought within a quarter of an inch from the end of the cable and the full voltage applied to the cable by means of T_1, T_2 and T_3 being at their zero position. The galvanometer showed a deflection which would be caused by less than one step on either controller, indicating that the maximum error is less than 2 per cent in the measurement of the smallest voltage read.

The sensitivity of the detecting device was such that after balance was obtained, an unbalance of one step (6 or 7 volts) on either transformer would definitely increase the galvanometer deflection.

The voltages on T_2 and T_3 should be at right angles to each other. To check this point, both transformers were raised to the same potential and readings taken of the separate voltages and of the hypothenuse voltage. This check was made at several different values with the reversing switches of both transformers in the up position, with both in the down position, and with one up and the other down.

The measured and calculated values checked exactly in some cases, and in others varied by as much as 3 per cent. This variation probably accounts for some small phase angle errors in the results.

A single-conductor cable was prepared with potential wires in the same manner as the three-conductor cables, and was supplied with voltage from phase A of T_1, T_2 and T_3 were used as balancing transformers, and the potentials determined at various distances from the conductor. In the ideal case T_2 should have been exactly in phase with phase A, and so the balance point should have been with zero voltage on T_3. However, T_3 was required to the extent of changing the phase of

T_2 about 1½ degrees on all the measurements. Correction was made for this error in plotting the curves.

The balancing transformers were connected successively with the three phases of T_1, the balancing transformers being grounded directly and T_1 being grounded through a condenser and the detecting circuit. The voltages were then balanced and readings taken on *V* and *C V*. These readings checked each other as closely as the instruments could be read.

After the three-phase tests were performed, the cable with circular conductors was dissected and one of the insulated conductors wrapped with foil, and measurements were made with single phase on layer *A* of potential wires. Calculation from values thus gotten indicated these potential wires to be 0.031 in. away from the conductor. Micrometer measurements indicated this distance to be 0.032 in. The dissection also showed that the potential wires were quite uniformly spaced around the conductor, but that they were not absolutely parallel with its axis, the rotation in the entire length being not more than half the distance between wires.

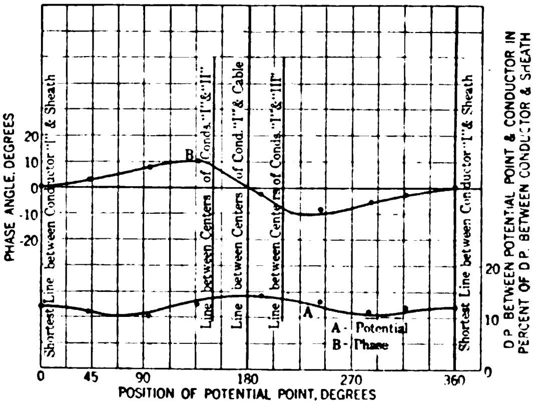

FIG. 22—PHASE AND POTENTIAL AT LAYER A, CONDUCTOR I, CIRCULAR CONDUCTOR CABLE

Dissection of the sector cable showed layer *D* of potential wires to be placed quite closely to their proper position, but that layer *A* was altogether misplaced. The actual positions were therefore accurately measured and used in Fig. 25. Micrometer measurements indicated the insulation thickness between the conductor and the first layer of potential wires to be 0.325 in. at the small diameter and 0.335 in. on the long diameter.

The curves, Figs. 22 to 25 inclusive, are as far as possible drawn from values obtained on one conductor only. The circles indicating the points for this conductor have been filled in solid. On all curves except Fig. 22 points also have been shown which were gotten on the other conductors.

In the case of the circular conductor cable, the relative positions of the potential points were found by dissection, but the exact location of the group with reference to a fixed line of the cable, such as the line between conductor center and cable center, was found from preliminary plotting of the phase measurements. It was known that the zero of the phase curve must occur at the point nearest the center of the cable and again at the point nearest the load. For the final curve the reference point of scale of abscissas was so taken that the phase curve would pass through zero on the said line.

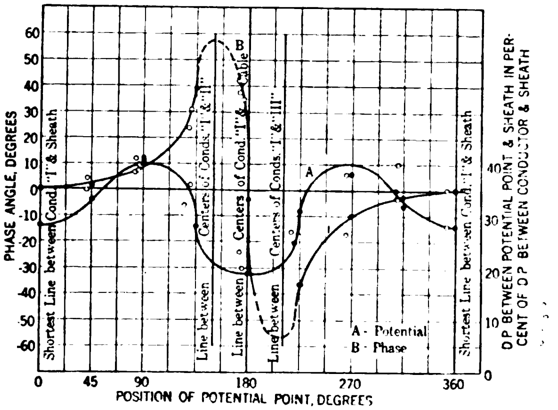

FIG. 23—PHASE AND POTENTIAL AT LAYER D, CONDUCTOR I, CIRCULAR CONDUCTOR CABLE

In the case of the sector cable, the relative positions of the potential points were, as in the other case found by dissection. However, since the shape of the cable furnishes a reference point, there was no difficulty in determining the reference point of the scale of abscissas from the measurements of the dissected cable. The zero of the phase curve is here seen to pass zero on the line of centers of conductor and cable, as was assumed in the case of the round conductor.

Curves were drawn of phase and of potential on layers *A* and *D* of both the circular conductor (Figs. 22 and 23) and sector (Figs. 24 and 25) cables. The ordinates of the phase curves are in electrical degrees, positive and negative; positive representing out of phase in one direction and negative in the other, as in similar curves from the tank experiments. The ordinates of the potential curves are in per cent of the voltage between conductor and sheath. The abscissas of the curves on the circular-conductor cable are in circular degrees, starting with 0 degrees at a point nearest the sheath, thus making the point nearest the center of the cable 180 degrees. In the case of the sector cable the zero is also taken at the point nearest the sheath, but the abscissas are in per cent of the perimeter at the layer of potential wires concerned. These curves should be symmetrical about their middle point, and any slight discrepancy may be attributed to non-symmetry of the three phases.

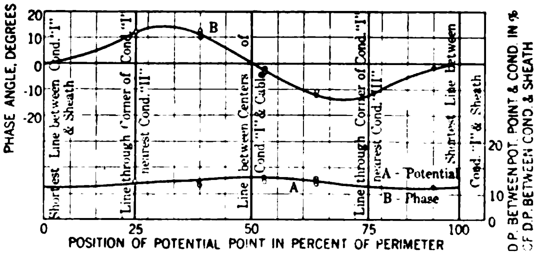

FIG. 24—PHASE AND POTENTIAL AT LAYER A, CONDUCTOR I, SECTOR CABLE

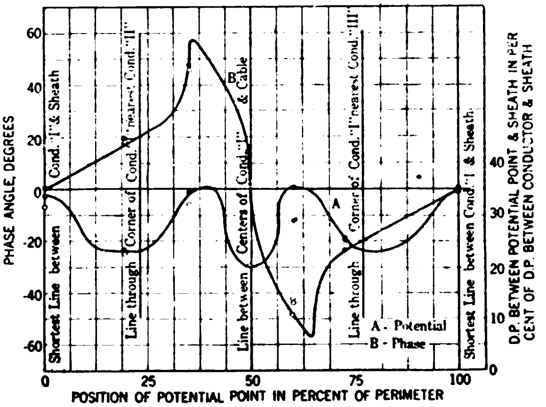

FIG. 25—PHASE AND POTENTIAL AT LAYER D, CONDUCTOR I, SECTOR CABLE

EFFECT OF STRANDING UPON STRESS

The data here recorded on the effect of stranding on voltage gradient are not extensive but supplement previous data. Tests were made on a seven-strand and a nineteen-strand conductor, that is one containing six wires and one containing twelve wires in the outer row. The ratio of the stress in the case of the stranded conductor to that with a round conductor of the same area of section and with the diameter of the sheath the same in each case, is given to compare with the value determined mathematically by Jona. The value 1.23 found for seven-strand conductor checks exactly with the value given by Jona. We find the same value for the 19-strand though Jona states the value will be larger, but he does not solve his equation for this case.

The most generally useful basis of comparison is the ratio of the stress of the stranded conductor to that of a round conductor of the same outside diameter and with the same insulation thickness. These values are given in the last column of the table. Little difference between the two styles of a stranding is apparent though the data are not on exactly the same basis. On ordinary thicknesses of insulation the increase of stress due to stranding is roughly 20 per cent. For very thick insulation relative to conductor diameter, the increase is greater and for thin insulation the increase is loss.

TABLE III
SHOWING EFFECT OF STRANDING UPON VOLTAGE GRADIENT

No. of Strands of conductor	Insulation thickness conductor diameter	Ratio of stress with stranded conductor to that with round conductor	
		A	B
7	1.47	1.23	1.26
7	0.50	1.23	1.18
19	1.07	1.21	1.22
19	0.71	1.22	1.20

A. Same outside diameter over insulation, area round solid equal to total area of strands.
B. Same outside diameter over insulation, same diameter of solid and stranded conductor.

Whitehead has shown that the effect of twisting the strands as is actually done in cable practise is to decrease the effect of stranding upon the gradient. Though his tests were with insulation thicknesses very great as compared to cable insulations, doubtless there is an important effect of this kind for thinner insulation. The data here given are upon untwisted strands and should be supplemented by determination of the effect of twisting. Data here given are for single-conductor cable in single-phase field.

PRACTICAL APPLICATION OF DATA

A brief outline of the manner in which the accompanying data may be applied to important problems is given.

The application of the resistance in electrolyte tank measurements has been indicated in the data given in connection with Fig. 2. This curve has been in use for some time in our laboratory and serves admirably to link together measurements of capacity, energy loss, etc. on different sizes, three-conductor cable as well as single-conductor cable. An interesting and important fact has been learned by the comparison thus allowed between the permittivity of the dielectric of three-conductor and single-conductor cable. It has been found that there is a definite difference, greater than the possible error of the curves in the direction of lower permittivity for the dielectric of the three-conductor form. This is attributed to a low permittivity of the filler material in actual three-core cable as compared with the uniform permittivity of the dielectric occupying the filler spaces in the tank of electrolyte, as we know that the filler of an actual cable may have lower permittivity than the paper on the conductor, under certain conditions. A more comprehensive investigation of this has been begun. The bearing of this upon the stresses in the cable is apparent and will be discussed further.

The application of these data to temperature rise measurements of three-conductor cable is similar and of corresponding convenience and value.

A table is given showing the stresses of a three-conductor cable under three-phase voltage, with the stresses of single-conductor cable of certain specified insulation thickness. Tests are reported on two sizes, one with relatively thin and one with relatively thick insulation. It will be observed that the maximum stress next the conductor, toward the cable center, is so close to that in a single-conductor cable having the same insulation thickness as the distance between conductor and center of cable, that quite accurate calculation of the stress of any three-conductor cable may be made readily from these data.

Data have been given showing the agreement between values determined from Russell and those measured, for maximum stress between conductor and sheath. A curve (Fig. 16) constituting a solution of Russell's formula is given.

Stresses at and near the center of the cable and at various points on the surface of the conductor insulation are seen to bear a fairly definite relation to the stress at the sheath of the same single-conductor cable. At the center, the stress is quite closely the same as that at the sheath of the single-conductor cable, though the stress at the other points is considerably greater.

When the stresses of the three-conductor cable are compared with those of a single-conductor cable, it should be remembered that, in many parts of the three-conductor cable there is not a simple alternating field, but it may be considered to consist of two alternating fields superimposed at right angles and producing a rotating electric field somewhat analogous to the rotating magnetic field of an induction motor.

TABLE IV.—STRESSES AT IMPORTANT POINTS IN SECTION

	r	*A*	*B*	*C*
Max. stress at conductor. Surface on line toward center of cable..............	0.625	1.71	1.01	2.65
	0.288	1.43	1.04	1.88
Stress at center of cable..............	0.625	0.65	0.385	1.01
	0.288	0.685	0.496	0.902
Stress at mid point between conductors on center line of conductors in direction of center lines...........................	0.625	0.92	0.545	1.42
	0.288	1.18	0.855	1.55
Stress at edge of conductor insulation on center line of conductor and center of cable................................	0.625	0.77	0.455	1.19
	0.288	0.83	0.602	1.09
Ditto but normal to the center line... .	0.625	0.51	0.302	0.790
	0.288	0.52	0.277	0.685

A. Stresses in terms of average stress between conductor and center of cable along line joining these points.

B. Stresses in terms of maximum stress of single conductor cable having the same insulation as the distance between the conductor and center of cable of three-conductor cable.

C. Stress in terms of minimum stress of single conductor having same insulation as *B*.

r. Ratio of conductor insulation to conductor diameter.

We have also summarized the data on the actual three-conductor cable so that they may be compared with those given in Fig. 11, as the result of the measurements with the conducting liquid.

It will be seen that the stresses next the conductor are somewhat greater than those determined by the previous method.

We are not able to state with certainty the reason for the difference, though we believe it too great to be accounted for by inaccuracy of measurements. If the permittivity of the filler material were higher rather than lower than that of the main insulation, it would result in giving such a result. As stated previously, it would be expected that this effect would be in the opposite direction, since for the low voltage at which measurements were made the filler was that thought to have a low permittivity. It is possible that the presence of the potential wires, due to the fact that they were not exactly parallel to the axis of the cable, distorted the field sufficiently to cause the increase of stress above the value found by the other method.

TABLE V

MEASURED STRESSES AT IMPORTANT POINTS IN ACTUAL CABLE

The data here given for the circular conductor cable for which curves have been shown. For this cable $r = 0.532$.

		AA	*A*	*B*
Stress at conductor on line joining center of conductor and center of cable.	From data	.87	1.70	1.05
Stress at conductor on.............	From Data	.75	1.46	.90
Shortest line between conductor and sheath..........................	From Russell's Formula	.70	....	.84

A, *B* and *r*—same as table above.

AA. Stress in terms of maximum stress of single-conductor cable with insulation thickness equal to conductor insulation or the 3 conductor cable.

NOTE. Data shown in column *AA* were obtained by comparing the three-phase stresses with stresses obtained by actual single-phase measurements on one of the conductors of the three-phase cable after it had been dismantled. Data shown in columns *A* and *B* were derived from the values in column *AA*.

It is important to consider the data on stresses in connection with the paper given before this Institute in February, 1919, by Shanklin and Matson. They conclude that the maximum allowable operating pressure for a given cable occurs at a certain gradient that is very definite for a given insulating material. If we accept this conclusion, we have at once from the data presented herewith, a basis for the relative rating of cable with different sizes of conductor and different thickness of insulation. However, the application of the data by one of the same authors, indicates that important modification of the said conclusion must be made. In the 1917 paper, a cable, No. 1/0 with

9/32 in. insulation on the conductors and 7/32-in. insulation on the belt is mentioned as having operated successfully at 24 kv. for some years, the maximum voltage gradient in this cable is more than 27 kv. per cm.—much in excess of 22 kv. which they conclude in the 1919 paper to be the limit for that class of material, as based on experiments on cable presumably of much more recent manufacture and therefore not of poorer construction. Of course also there are many other cables operating successfully at gradients much in excess of 22 kv. per cm.

In bringing out this point in connection wth the paper of Shanklin and Matson, I do not want to be misunderstood, as I consider their paper an important contribution to the problem of cable insulation; and though I feel that the theory offered must be subjected to material modification, yet it may be part of the foundation upon which may grow a material evolution in the cable industry.

While considering this paper by Messrs. Shanklin and Matson, it may be well to call attention to the possibility that, in some cases, the ionization which they found occurred actually in the filler spaces rather than next to the conductors. It is not possible to give specific figures, as we do not now have sufficient data of stresses in the filler space with single-phase voltage which is the condition under which their measurements were made.

SECTOR CABLE

We are not attempting to give as specific data on sector cable as have been given for round. Time and space make a barrier and furthermore specific data will have less general application, for the terms "sector" and "modified sector" as applied to cable conductors are given to shapes differing quite widely in form and thus in characteristics, and presentation of complete data on even one specific form of conductor would require even more space than for round conductors. Some approximate general statements will however be of value.

To determine capacitance of cables with conductors of sector shape, take the data for a cable with the same insulation thickness and with round conductors of about 50 per cent (two sizes A. W. G.) greater area than the sector conductor. Actually for different insulation thicknesses relative to conductor sizes and for capacities of the different combinations listed, there is much range in the ratio of areas of round conductors and sector conductors having the same capacitance, the range of this ratio being from about 1.2 to 2.0, hence the rule just given is not more than a first approximation though it will seldom give capacities greatly in error.

The measurements made on the sample of actual sector cable indicate that the maximum stress is somewhat lower than that for the corresponding round conductor cable but tests in the electrolyte tank indicate that relatively slight change of shape can influence the value of maximum stress sufficiently to vary it from lower to higher than for round conductor. The stress on the outer surface next the sheath was in all cases much less than for the round conductor.

Attention has been called above to the fact that these data throws much light on the inherent weakness of the ordinary form of three-conductor cable. The stresses in the filler spaces and tangential to the layer insulation are somewhat less than the maximum which occur at conductor surface. However, because of the weakness of the filler insulation and the weakness of the conductor insulation for tangential stress, these stresses become of great importance. The stresses in filler space are very large as compared with the average stress throughout the insulation and large even as compared with the maximum values at the conductor surface. Improvement in this portion of the dielectric has not in the past kept pace with improvement in the insulation near the conductors and probably can still not do so in the future. Doubtless, therefore, stresses in this portion of the cross section will become more and more the limiting condition in cables of the usual three-conductor form. Furthermore it must be borne in mind that the stresses given are for the condition of dielectric of uniform permittivity. The stresses in the filler space will exceed materially the values here found, where the permittivity of the filler material is lower than that of the remainder of the insulation.

These experiments were carried on in the factory, and the writer wishes to express appreciation for the facilities extended by his Company, and for the cooperation of various individuals. Thanks are due Mr. C. W. Davis and Mr. H. W. Fisher for many valuable suggestions and comments, to Mr. Donald Simons in connection with the early work done in Pittsburgh Laboratory, and to Mr. A. M. Hagen and Mr. L. Meyerhoff for their faithful and valuable assistance in the performance of experimental work in the preparation of this paper.

REPORT OF THE BOARD OF DIRECTORS

FOR THE FISCAL YEAR ENDING APRIL 30, 1919

The Board of Directors of the American Institute of Electrical Engineers presents herewith to the membership its Thirty-fifth Annual Report, for the fiscal year ending April 30, 1919. A general balance sheet showing the condition of the Institute's finances on April 30, 1919, together with other detailed financial statements, is included herein.

Directors' Meetings.—The Board of Directors held ten regular meetings during the year; seven of these were held in New York, one in Atlantic City in June, one in Philadelphia in December, and one in Boston in March.

The practise has been continued of printing from month to month in Section I of the Institute PROCEEDINGS information regarding the more important activities of the Institute which have been under consideration of the Board of Directors, the committees, and the various officers.

Annual Meeting.—The Annual Business Meeting was held at Institute headquarters, New York, on May 17, 1918. The Annual Report of the Board of Directors for the fiscal year ending April 30, 1918, was presented as published in full in the June 1918 issue of the PROCEEDINGS. The Tellers Committee presented its report upon the election of officers for the year beginning August 1, 1918.

Directly following the business meeting came the ceremony of the presentation of the Edison Medal to Colonel John J. Carty.

Annual Convention.—The Thirty-fourth Annual Convention was held at Atlantic City on June 26 to 28, 1918. This was strictly a business meeting at which 15 technical papers were presented at five sessions. Several meetings of the Section Delegates were held. Major General Black delivered an address on "Engineers and the War."

October Meeting.—The 342nd Institute meeting, scheduled to be held at Philadelphia, October 11 and 12, 1918, was cancelled on account of the influenza epidemic. Presentation of the technical papers was postponed until the meeting of December 13, 1918.

New York Meeting.—The 343rd Institute meeting was held in New York on November 8, 1918 under auspices of the Industrial and Domestic Power Committee.

Toronto Meeting.—The 344th Institute meeting was held in Toronto, Ontario on November 22 and 23, 1918. Three technical papers were presented on power installations and developments in Ontario and Quebec.

Philadelphia Meeting.—The 345th Institute meeting was held in Philadelphia on December 13, 1918. Two technical papers were presented and two addresses on Research.

New York Meeting.—The 346th Institute meeting was held in New York on January 10, 1919. The evening was devoted to an address by Major General Squier on aeronautics.

Mid-Winter Convention.—The Seventh Mid-Winter Convention was held in New York on February 19 to 21, 1919. Attendance exceeded 1300. Four technical sessions were held and fifteen papers presented. The first session was held jointly with the A. I. M. E. A complete report of this convention was published in the March 1919 PROCEEDINGS.

Boston Meeting.—The 348th Institute meeting was held at Boston on March 14, 1919. Morning, afternoon and evening sessions were held at which three technical papers and several addresses were presented on widely divergent topics.

New York Meeting.—The 349th Institute meeting was a joint meeting with the Illuminating Engineering Society held at New York on April 11, 1919. One paper was presented on the subject of Lighting Codes.

Meetings and Papers Committee.—The Meetings and Papers Committee has held meetings every month at the time and place of the regular meetings of the Institute held during the past year as referred to above. At these Committee meetings the programs of the Institute meetings were planned and the various papers offered for presentation and the policy of the Committee were discussed. The policy of the Committee has been to continue the practise of holding some meetings outside of New York; one was held in Toronto in November, one in Philadelphia in December, and one in Boston in March.

At the beginning of the fiscal year the Committee found that owing to the war activities of the membership it was very difficult to get good papers, but with the cessation of war activities a considerable number of desirable papers were offered. After completing plans for all the meetings through and including November 1919, a considerable number of papers is still available. In fact there is material available for some Section meetings, which the Committee would like to encourage in order that certain papers well worthy of presentation may be presented at an earlier date than would be the case if they had to wait for the regular Institute meetings.

A Pacific Coast Convention, to be held in Los Angeles in September 1919, has been authorized.

Technical Activities.—The Board of Directors' Committee on Technical Activities was appointed for the purpose of co-relating the work of the various Technical Committees and to bring about the adoption of programs of work for the Committees to undertake, which might prove of advantage to the Institute. In the past the Technical Committees have been mainly concerned with securing papers for meetings and with few exceptions there have been no other activities. It has been realized for a long time that there were other fields that the Technical Committees could work in to the advantage of the Institute. Some committees had already undertaken programs mainly with the object of preparing statements of existing successful practise for the guidance of people interested in various industries, but in the past it has not always been possible to carry out such programs, as there was no system for insuring the continuity of such action. The Board's Committee has communicated with the Chairmen of Technical Committees during the year and there has been an increase in the amount of work undertaken by these committees. The Industrial Power Committee has had for sometime a large program which is being worked out, and the other committees have started work along somewhat similar lines, such as the Iron and Steel Committee, which is preparing to summarize the successful practise of the Iron and Steel Industry with regard to electrical installations; the Marine Committee which has been engaged in preparing proposed installation rules for which there is at present a great need, and others of the Committees are engaged on similar useful programs which will be presented to the Institute either in the form of papers or reports.

The Annual Reports of the sixteen technical committees of the Institute will be presented at the Annual Convention of the Institute in June 1919, and will probably be printed in the July or August issues of the PROCEEDINGS.

Editing Committee.—The Editing Committee has jurisdiction over the publication of the annual TRANSACTIONS and has been engaged with Volume XXXVII covering the year 1918. This volume will be published in two parts, Part I is completed and Part II is now in the bindery. The volume contains approximately 2000 pages and 87 plates of half-tone illustrations, comprising papers and discussions presented at Institute meetings during the year.

Sections Committee.—The year ending May 1st witnessed the crest of the wave of American activity in the great war. It is then not surprising that it should include the slight resulting depression in attendance at the meetings of the various sections of the Institute indicated in the table below.

Whether drawn from the lessons of the hour regarding the value of co-operation or led by some other inspiration, the tendency in section affairs during the year has been that of continued development in the direction of affiliation with the sections of other technical societies. This has resulted not only in the highly desirable objective of greater co-operation and unity among engineers, but has also placed the engineer in higher standing with his community by his greater participation in civic and municipal affairs in those centers where such affiliation has been undertaken.

The Sections Committee, encouraged by the well established policy of the Institute which has long aimed to develop this co-operation, appointed at their conference at Atlantic City last June, a committee to study existing methods and formulate suggestions for the guidance of all sections so located as to make such affiliation profitable.

This committee, now working in conjunction with the general committee on the development of Institute activities, should be able to tender a helpful report at the meeting of the sections delegates next month. The sections at Atlanta, Chicago, Milwaukee, St. Louis, Spokane, Indianapolis, Philadelphia, Portland, Ore., and San Francisco, now well established in this plan of affiliation should find numerous additions to their ranks as time progresses.

The activities of the Student Branches have continued to be materially modified by the war conditions, notably by the organization of the Students Army Training Corps. A considerable number of the Branches have been inactive during the greater portion of the year, but since January 1, many have reorganized and are now active; all will probably resume normal activity by next Fall.

Two new Branches were authorized during the year at the University of Pennsylvania and Drexel Institute.

	For Fiscal Year Ending						
	May 1 1913	May 1 1914	May 1 1915	May 1 1916	May 1 1917	May 1 1918	May 1 1919
SECTIONS							
Number of Sections.........	29	30	31	32	32	34	34
Number of Section meetings held....................	244	233	246	251	265	245	217
Total Attendance..........	22,825	22,626	23,507	28,553	31,299	34,614	25,837
BRANCHES							
Number of Branches	47	47	52	54	59	59	61
Number of Branch meetings held....................	357	306	328	360	368	268	156
Attendance................	11,808	11,617	12,712	15,166	16,107	10,683	6,441

Standards Committee.—The Standards Committee has held during the year six regular monthly meetings, one special meeting, and a joint meeting with the U. S. National ***Reorganization of Work.***

In order to expedite the work of the Committee, the entire system of subcommittees has been reorganized so that all detail consideration of changes in standards and other technical affairs is now referred in each case to a specific sub-committee. Action by the Standards Committee is taken only after receiving recommendations from a subcommittee. A large amount of detail discussion has thus been eliminated. There are at present twenty-four of these sub-committees.

Revision of the General Form of the Standardization Rules.—A large share of the time of the Standards Committee during the past year has been devoted to a consideration of changes in the form and arrangement of the Standardization Rules. This matter has been in the hands of the Subcommittee on the *Form but not the Substance* for some time past and a general system of revision by which the Standardization Rules are divided into chapters was reported and has been adopted.

Changes in Substance of the Present Rules.—It is hoped to complete the full text of this revision of the form of the Standardization Rules this year. A few minor changes of substance will be included.

A revised chapter covering Lighting and Illumination and based on the latest rules of the Illuminating Engineering Society has been recommended by the Subcommittee on Lighting and Illumination and substituted for the present chapter.

Cooperation with the General Committee on Standardization of Electrical Equipment and Supplies of the War Department.—At the request of Major N. J. Neall, Chairman of the above Committee, that the Standards Committee should cooperate with the General Committee of the War Department in the preparation of specifications, the Standards Committee voted to render all possible assistance through its subcommittees. Dr. P. G. Agnew was appointed a special subcommittee to further this work which has been carried on throughout the year. Very effective assistance has been rendered the War Department Committee.

Joint Meeting with U. S. National Committee of the I. E. C.—At a joint meeting of the U. S. National Committee of the I. E. C. and the Standards Committee it was decided to recommend the early reappointment of the subcommittee of the I. E. C. on Rating, to meet preferably in Paris. Professor C. A. Adams, Mr. H. M. Hobart and C. O. Mailloux will represent the Institute. These representatives while abroad will also take up with the Rating Panel of the British Engineering Standards Association the actions taken and suggestions made by the Standards Committee.

American Engineering Standards Committee.—The consideration of suggested changes in the Constitution and Rules of Procedure made it necessary to continue the organization committee until May 1918, when a revised draft of the Constitution and Rules of Procedure was agreed upon and sent to the five appointing societies (A. S. C. E., A. I. M. M. E., A. S. M. E., A. I. E. E., and A. S. T. M.) for their approval. This approval was received from all of the societies, and representatives appointed by each met on October 19th, 1918, and organized the American Engineering Standards Committee.

Soon after organization it became evident that the Committee must be enlarged in order to secure the cooperation of several important organizations engaged in standardization work. This fact was emphasized by the action of a conference held in Washington, January 15, 1919, to consider the method of developing and approving Industrial Safety Codes. At this conference it developed that the principal organizations would not cooperate with this Committee unless they had direct representation on it. Such representation is not possible under the present Constitution, so after careful consideration the Committee has decided that an increase in its membership is desirable. It will therefore be necessary to make further changes in the Constitution. Such a revision has been drafted and approved by the Committee and will be submitted to the five Founder

Societies for their approval during the month of May 1919. It is expected that this revision will enable the Committee to begin active work in the near future.

Public Policy Committee.—The Public Policy Committee, during the administrative year about to close, has held itself in readiness to take up any matters which might be referred to it by the Institute authorities, but has not initiated any recommendations. The reason for the inactivity of the Committee is that for the last two years the several matters which would have naturally been acted upon by it have been considered by Engineering Council.

Committee on Safety Codes.—The Committee on Safety Codes has continued to represent the Institute on the Electrical Committee of the National Fire Protection Association, and representatives attended the meeting of the N. F. P. A. Committee in New York in March, this being the intermediate meeting, at which was discussed the various features of the Electrical Code, in preparation for the regular biennial meeting in 1920, at which time changes in the Code are officially made.

The Committee was represented at the conference in Washington with the Bureau of Standards, for the purpose of discussing matters relating to the American Engineering Standards Committee, and the desirability of the writing of an Industrial Safety Code.

The Committee has been active during the year on routine matters of a code nature, with the N. E. L. A.

The first part of the fiscal year the Committee was more or less inactive, due to war conditions, but since the signing of the armistice inter-association matters have revived, and almost all the activities of the Committee occurred in the last quarter of the year.

Board of Examiners.—The Board of Examiners during the year held sixteen meetings, averaging about two and one-half hours each. It considered and referred to the Board of Directors a total of 2111 applications for admission or transfer to the higher grades.

Some applicants for admission were objected to on ethical grounds. Although the number of such cases was small, considerable time was required for the necessary investigations; adverse action was taken in a few such cases. The Board continued the practise of requiring questionable applicants to furnish proof of loyalty to the ideals of the United States.

The result of the Board's work for the year is given in the following tabulated statement:

APPLICATIONS FOR ADMISSION

Recommended for grade of Associate	1213	
Not recommended	9	1222
Recommended for grade of Member	87	
Not recommended for admission to this grade	23	110
Recommended for grade of Fellow	4	
Not recommended for admission to this grade	1	5
Recommended for enrolment as Students		659

APPLICATIONS FOR TRANSFER

Recommended for grade of Member	81	
Not recommended for transfer to this grade	19	100
Recommended for grade of Fellow	12	
Not recommended for transfer to this grade	3	15
Total number of applications considered		2111
Applications reconsidered		6
Total		2117

Membership.—Sixteen hundred and ninety-five applications for membership in the Institute have been received this year, which is by far the largest number ever received in any one year. The nearest approach to this was for the year ending May 1, 1918, when 1235 applications were received.

A printed list of reasons why a man should become a member of the Institute was printed for distribution to desirable candidates. Several thousand of these were called for by the Sections.

The Membership Committee feels that new members should be obtained at an increasing rate to keep pace with the industry.

The 10,000 mark has been passed, the membership of the Institute as of May 1, 1919, being 10,352. This shows a net increase of 1070 members since May 1, 1918, approximately twice the net increase of the previous year, which was 572.

During the five years ending May 1, 1917, the net increase was only 1251; the total applications received in these five years, 2440. These figures emphasize the greatly increased activity of the past two years.

	Honorary Member	Fellow	Member	Associate	Total
Membership, April 30, 1918	6	464	1332	7480	9282
Additions:					
Transferred	....	24	88	....	....
New Members Qualified		6	84	1321	....
Reinstated	....	4	7	55	....
Deductions:					
Died	....	4	7	66	....
Resigned	....	1	4	77	....
Transferred	....	....	18	94	....
Dropped	....	4	15	229	....
Membership, April 30, 1919	6	489	1467	8390	10352

Net increase in membership during the year..1070

Deaths.—The following deaths have occurred during the year:

Fellows—A. O. Benecke, M. H. Collbohm, W. L. Hooper, C. R. McKay.

Members—George E. Claflin, *F. J. Duffy, Charles H. Hile, W. J. Jenks, Etna Kuhlman, Frank I. Porter, O. O. Rider.

Associates—E. G. Anderson, H. F. Anderson, Arthur S. Andrews, Samuel Avis, G. R. Baker, *Remson Bishop, John Bottomley, Ralph E. Brown, W. B. Burbeck, *E. W. Caldwell, J. J. Campbell, Eric Carlson, *Lucian Carr, *W. W. Crawford, E. W. Currier, Harry L. Curtis, *R. F. Day, Edward D. Donald, *John J. Donnohue, Hugh H. Emery, E. B. Fahnestock, I. Fujioka, John D. Gaboury, W. K. Greenwood, John Hanover, Vernon E. Hess, W. Lesniewski, Edward Lineberry, Claudius B. Little, *George Mac Indoe, J. A. MacQueen, Glen W. Merrill, *Charles J. Moore, A. F. Moray, *N. I. Moultrop, H. P. Myers, Archie Oakes, B. A. Ordonez, C. H. Parmly, D. H. Plank, James M. Poyner, H. E. Randall, Jr., O. B. Reynolds, E. M. Rhett, Arnold Ruegg, Owen Samsel, Charles P. Seeger, S. V. Setti, *D. A. Shanks, C. F. Shipman, Charles F. Sise, *J. C. M. Small, Herbert E. Smith, Alan Smout, C. W. Steiner, John F. Stevens, S. Sugiyana, T. R. Taltavall, Ralph E. Thomas, *A. R. Thompson, Stuart Thomson, L. J. Vogel, H. Webber, F. S. Wheeler, Richard M. Wilson, Minor I. Woodward, N. R. Work.

Total deaths, 77. *Died in U. S. Service.

Employment Service.—An employment service has been maintained for many years at Institute headquarters for the purpose of assisting members in obtaining positions. The services of the Institute consist principally in acting as a medium for bringing together the employer and the employee. No charge is made.

The engineering service bulletin is published each month in the Institute PROCEEDINGS and it has served to place many men in positions of responsibility, both in this country and abroad. The bulletin is subdivided into two parts: one containing announcements of vacancies, and the other containing lists of men available, with condensed records of their experience. The value of this service to the membership will continue to increase from year to year as men of engineering and executive responsibility realize the opportunity afforded by it to reach technical men whom it would be difficult to find through other channels.

Demobilization greatly increased the number of men available, while the number of positions open has greatly decreased. The service has been extended without charge to non-members who are or have been in the service of the Army or Navy. An effort has been made to keep those men on the available file in closer touch with positions open than heretofore possible when dependence was alone placed on the Service Bulletin of the PROCEEDINGS, by issuing to them when deemed advisable, a list of the opportunities on file.

The Institute's employment service is coordinated with that of other organizations, through the medium of the Engineering Societies Employment Bureau, organized under the auspices of the Engineering Council and conducted under the direction of the secretaries of the national societies of Civil, Mining, Mechanical, and Electrical Engineers.

Development of the Institute.—In October 1918 the Board of Directors authorized the appointment of a Committee on Development to consider suggested or proposed modifications in the activities and methods of work of the Institute, including the relations of the Institute to other organizations. This action was taken with a view to making a survey of, and adjusting, the work of the Institute, having in mind the rapidly changing social, economic, and industrial conditions.

Each Section of the Institute was requested to designate a member of this Committee; and these representatives of Sections, together with seven additional members appointed by the President, constitute the Committee, which has been actively at work for several months. The membership was urged to submit suggestions and most of the Sections have held at least one meeting for the purpose of discussing the subject. On account of the wide geographical distribution of the membership, no meetings of the entire Committee have been held, but the representatives of the Sections have made reports to an Executive Committee of seven members of the Development Committee. This Executive Committee has held two meetings, at which numerous suggestions from the membership throughout the country have been considered. The principal features of these suggestions representing the consensus of the views expressed, are being compiled by the Executive Committee for further consideration by the members of the general Committee; and the whole subject will be thoroughly considered and discussed in conferences to be held under the auspices of the Development Committee at the Annual Convention of the Institute in June, after which it is expected that a report, embodying definite recommendations, will be presented to the Board of Directors.

War Activities.—The Institute continued during the past year in active cooperation with the various government departments and agencies engaged in war work as listed in the Report of the Board of Directors for 1918.

The work in furtherance of Allied victory in which the Institute aided during the period from May 1918 to the signing of the armistice included cooperation in obtaining personnel for many branches of service, as follows: candidates for the 4th series of Officers Training Schools, for Submarine Service, for the Coast Artillery Corps and the Forest Service; specially trained men for work in the Bureau of Mines and to act as instructors in the various army training schools; for the U. S. Navy Steam Engineering School at Stevens Institute and for commissions in the Ordnance Dept.

The compilation and correction of the Institute's Honor Roll has been continued until from all information at hand it shows a total of 1417 members have served in the uniformed forces of the United States and the Allies of which number 21 died in service. Practically all of the 1417 members voluntarily entered the service and it is particularly gratifying to note the large proportion of officers, as given in the summary. A large proportion of these officers received their commissions, or were inducted into the service as a result of calls made upon the Institute by various departments of the Army and Navy.

SUMMARY

U. S. ARMY

Major Generals	7
Brigadier Generals	5
Colonels	9
Lieut. Colonels	23
Majors	110
Captains	219
First Lieutenants	199
Second Lieutenants	162
Sergeants	34
Corporals	17
Miscellaneous	267
Total	1052

U. S. NAVY

Rear Admirals	1
Captains	1
Commanders	6
Lieut. Commanders	9
Lieutenants	45
Lieutenants (j. g.)	72
Ensigns	75
Miscellaneous	75
Total	284

U. S. MARINE CORPS

Lieutenants	3
Private	1
Total	4

ALLIED FORCES

British Army	63
British Navy	6
French Army	6
Italian Army	1
Japanese Navy	1
Total	77

Total on Honor Roll..............1417

U. S. National Committee, International Electrotechnical Commission.—The U. S. National Committee of the I. E. C. held a joint meeting with the Standards Committee in Philadelphia, December 12, 1918, at which resolutions were adopted favoring the resumption of I. E. C. activities, and recommending the early reappointment of a subcommittee of the I. E. C. on Rating, to meet preferably in Paris, for the purpose of considering certain communications from the French Committee, particularly in regard to I. E. C. rules on Temperature Elevations of Machinery.

At this meeting, the printing of the I. E. C. Rating Rules as an appendix to the 1918 edition of the A. I. E. E. Standardization Rules, was suggested and authorized.

The following documents have been received from the General Secretary and distributed among the members of the U. S. National Committee:

(1) The Annual Report of the Honorary Secretary (Colonel Crompton) for the year 1918.

(2) A communication from the French Committee regarding a term for the unit of "Reactive Power."

(3) A list of Statutes of the I. E. C.

(4) A communication from the Dutch Committee in regard to an international standard of comparison of aluminum.

The U. S. National Committee will be represented by Messrs. C. A. Adams, H. M. Hobart, and C. O. Mailloux at a meeting of the I. E. C. Special Committee on Rating, at Paris, May 5-7, 1919.

It is believed that the conventions of I. E. C., interrupted for more than four years by the war, will now be resumed.

American Engineers Go To France.—At the invitation of the French Society of Civil Engineers and a committee of the French Engineers' Congress, and with the approval of the French government, a delegation of American engineers was appointed to study with French engineers problems involved in the industrial rehabilitation of France; such as, utilization of commercial ports, the development of navigable waterways, the development of water power, improvement of road systems, and many other questions of development.

Immediately on receipt of the invitation a delegation was organized representing the American national societies. The Executive Committee of the Institute selected Lewis B. Stillwell as the A. I. E. E. representative. The complete delegation, which sailed from New York on December 5, 1918, was, as follows: Messrs. James F. Case, Chairman, Geo. W. Fuller, A. M. Hunt, Nelson P. Lewis, Charles T. Main, E. Gybbon Spilsbury, Lewis B. Stillwell, George F. Swain, and George W. Tillson.

On the evening of February 10, 1919 a joint meeting of the four Founder Societies was held in the Engineering Societies Building, New York, at which the delegates presented informal reports, abstracts of which were published in the PROCEEDINGS for March, 1919.

United Engineering Society.—This Society performs for the national societies of Civil, Mining, Mechanical, and Electrical Engineers, certain specific acts which are governed by contracts; the primary function of the United Society being to hold in trust and to administer for these societies the Engineering Societies Building, in which the headquarters of the national societies are located.

Extracts from the annual financial report of the United Engineering Society were published in the April 1919 PROCEEDINGS.

Library.—The library of the Institute is combined with the libraries of the national societies of civil, mining, and mechanical engineers, administered as the "Engineering Societies Library" under the direction of the Library Board of the United Engineering Society; this board is composed of representatives of each of the four societies referred to above.

In order to place the facilities of the library at the disposal of persons residing at a distance from New York, a Library Service Bureau has been established, and a staff of expert searchers and translators is employed to cover almost any engineering topic, in the following manner: abstracting, translating, bibliographing, statistical searches and reports, searches for patent purposes, copying, preparing reference cards, etc.

An abstract of the annual report of the Engineering Societies Library covering the calendar year 1918, was published in the April 1919 PROCEEDINGS.

Engineering Council.—The Engineering Council represents the result of an organized effort inaugurated in the latter part of 1916 by the national societies of Civil, Mining, Mechanical, and Electrical Engineers, to establish an instrument through which united action could be brought about upon matters of common interest to engineers and which would serve as a connecting medium between the engineer and the public welfare in matters of interest to the engineering profession. The first meeting of the Council was held on June 27, 1917.

For details regarding the field, aims, and activities of the Council, members are referred to the numerous statements published from time to time in the monthly Institute PROCEEDINGS. A resume of the annual report covering the activities of the Council for the year ending February 13, 1919, was published in the April 1919 PROCEEDINGS.

Engineering Foundation.—The Engineering Foundation is a fund established by the United Engineering Society on January 27, 1915, through the generosity of Mr. Ambrose Swasey, of Cleveland.

The purpose of the Engineering Foundation is the advancement of the engineering arts and sciences in all their branches to the greatest good of the engineering profession and the good of mankind, which it is proposed to accomplish largely through the promotion of engineering research.

The Engineering Foundation is administered by a board upon which the Institute and other national engineering societies are represented. The annual report of the Engineering Foundation was also published in the April 1919 PROCEEDINGS.

Representatives.—The Institute has continued its representation upon various national committees and other local and national bodies with which it has been affiliated in past years, and in addition has appointed representatives upon a number of new organizations, some of the more recent being the Engineering Division of the National Research Council, and the American Bureau of Welding.

Edison Medal.—The Edison Medal for 1917, which had been awarded to Col. John J. Carty "for his work in the science and art of telephone engineering" was presented to Col. Carty with appropriate ceremonies at the Annual Meeting of the Institute held in New York on May 17, 1918.

The Edison Medal for 1918, has been awarded to Benjamin G. Lamme "for invention and development of electrical machinery," and the presentation will take place at the Annual Meeting of the Institute which will be held in New York on May 16, 1919.

John Fritz Medal.—The John Fritz Medal Board of Award which is composed of representatives of the national societies of Civil, Mining, Mechanical and Electrical Engineers awarded the 1919 medal to General George W. Goethals, the builder of the Panama Canal. The presentation will take place at the Engineering Societies Building in New York on May 22, 1919.

Finance Committee.—During the year the committee has held monthly meetings, has passed upon the expenditures of the Institute for various purposes, and otherwise performed the duties prescribed for it in the Constitution and By-laws.

Haskins and Sells, certified public accountants, have audited the books, and their report is included herein.

HASKINS & SELLS
CERTIFIED PUBLIC ACCOUNTANTS
CABLE ADDRESS "HASKSELLS"
30 BROAD STREET
NEW YORK

NEW YORK
CHICAGO
DETROIT
SAINT LOUIS
BOSTON
CLEVELAND
BALTIMORE
PITTSBURGH

SAN FRANCISCO
LOS ANGELES
NEW ORLEANS
SEATTLE
DENVER
ATLANTA
WATERTOWN
LONDON

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

CERTIFICATE OF AUDIT

We have audited the books and accounts of the American Institute of Electrical Engineers for the year ended April 30, 1919, and

WE HEREBY CERTIFY that the accompanying General Balance Sheet properly sets forth the financial condition of the Institute on April 30, 1919, that the Statement of Income and Profit & Loss for the year ended that date is correct, and that the books of the Institute are in agreement therewith.

HASKINS & SELLS,
Certified Public Accountants.

NEW YORK,
May 13, 1919.

AMERICAN INSTITUTE OF

EXHIBIT A.

GENERAL BALANCE SHEET

ASSETS

REAL ESTATE:			
One-fourth Interest in United Engineering Society's Real Estate, 25 to 33 West 39th Street:			
Land and Building		$472,500.00	
Real Estate Equipment		14,292.79	
Total Real Estate			$486,792.79
EQUIPMENT:			
Library—Volumes and Fixtures		$ 39,847.55	
Works of Art, Paintings, etc.		3,001.35	
Office Furniture and Fixtures		12,428.68	
Total		$ 55,277.58	
Less Reserve for Depreciation		10,840.47	
Remainder—Equipment			44,437.11
INVESTMENTS:			
Bonds—City of Wilmington, Delaware, 4½%, 1934, Par Value $15,000.00		$ 15,782.05	
United States Third Liberty Loan, 4¼% Bonds		10,000.00	
Total Investments			25,782.05
WORKING ASSETS:			
Publications Entitled "Transactions," etc.		$ 12,599.00	
Paper and Cover Paper		2,162.05	
Paper for Volume 37 and Advertising		336.69	
Badges		1,166.74	
Total Working Assets			16,264.48
CURRENT ASSETS:			
Cash		$ 14,916.68	
Accounts Receivable:			
Members for Past Dues		9,728.15	
Advertisers		678.80	
Miscellaneous Sales		388.09	
Miscellaneous Printing and Subscriptions		1,034.00	
Accrued Interest on Investments		109.38	
Accrued Interest on Bank Balances		284.59	
Total Current Assets			27,139.69
FUNDS:			
Life Membership Fund			
Cash	$ 438.67		
Chicago, Burlington & Quincy Railroad Company Bonds, 4%, 1958, Par Value $5,000.00	4,868.75		
Accrued Interest	33.33	$ 5,340.75	
International Electrical Congress of St. Louis—Library Fund:			
Cash	$ 137.61		
New York City Bonds, 4½%, 1957, Par Value $2,000.00	2,242.33		
New York Telephone Company Bond, 4½%, 1939, Par Value $1,000.00	878.75		
Accrued Interest	67.50	3,326.19	
MAILLOUX FUND:			
Cash	$ 142.35		
New York Telephone Company Bond, 4½%, 1939	1,000.00		
Accrued Interest	22.50	1,164.85	
Midwinter Convention Fund—Cash		135.89	
Total Funds			9,967.68
DUES PAID IN ADVANCE—INTERNATIONAL ELECTROTECHNICAL COMMISSION, LONDON, ENGLAND			250.00
Total			**$610,633.80**

ELECTRICAL ENGINEERS.

April 30, 1919.

Liabilities

Current Liabilities:		
Accounts Payable—Subject to Approval by the Finance Committee	$ 6,362.87	
Due United Engineering Society, Account Building Addition, Including Accrued Interest	7,625.75	
Dues Received in Advance	2,805.45	
Entrance Fees and Dues Advanced by Applicants for Membership	455.50	
Total Current Liabilities		$ 17,249.57
Fund Reserves:		
Life Membership Fund	$ 5,340.75	
International Electrical Congress of St. Louis—Library Fund	3,326.19	
Mailloux Fund	1,164.85	
Midwinter Convention Fund	135.89	
Total Fund Reserves		9,967.68
Surplus: Per Exhibit "B"		583,416.55
Total		$610,633.80

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

STATEMENT OF INCOME AND PROFIT AND LOSS.

FOR THE YEAR ENDED APRIL 30, 1919.

EXHIBIT B.

REVENUE:			
Entrance Fees		$ 7,225.00	
Dues		102,908.43	
Students Dues		4,044.00	
Transfer Fees		1,060.00	
Advertising		10,641.33	
Subscriptions		3,144.92	
Sales of "Transactions," etc.		2,954.80	
Badges Sold	$3,285.75		
Less Cost	2,387.83	897.92	
Interest on Investments		1,089.61	
Interest on Bank Balances		936.40	
Exchange		41.91	
Total			$134,944.32
EXPENSES:			
Meetings and Papers Committee:			
Salaries		$ 5,940.00	
Binding and Mailing "Proceedings"		5,887.20	
Printing "Proceedings"		8,947.43	
Engraving "Proceedings"		2,549.13	
Paper and Cover Paper		8,342.44	
Envelopes		882.18	
Stationery and Miscellaneous Printing		378.53	
General Expense		348.03	
Meetings		6,115.33	
Total			$ 39,390.27
EDITING COMMITTEE:			
Volume No. 34		$ 56.19	
Volume No. 35		48.63	
Volume No. 36		4,721.88	
Volume No. 37		7,062.51	
Total		$ 11,889.21	
Add Decrease in Inventory:			
April 30, 1918	$14,049.00		
April 30, 1919	12,599.00	1,450.00	13,339.21
EXECUTIVE DEPARTMENT:			
Salaries		$ 19,805.00	
General Expense		2,097.24	
Express		371.17	
Postage		2,479.30	
Advertising		3,371.90	
Stationery and Miscellaneous Printing		4,019.83	
Year Book and Catalogue		4,597.61	
Total			36,742.05
FORWARD			$ 89,471.53
TOTAL REVENUE—(Forward)			$134,944.32

Total Revenue—(Forward)		$134,944.32
Expenses—(Forward)		$ 89,471.53
Sections Committee:		
Sections Meeting	$ 6,230.07	
Branch Meetings	81.11	
Delegates Convention Expense	3,286.44	
Salaries, New York Office	2,340.00	
Stationery and Printing, New York Office	768.46	
Total		12,706.08
United Engineering Society:		
Assessment	$ 4,800.00	
Library Committee	4,000.00	
Engineering Council	3,733.36	
Total		12,533.36
General:		
Membership Committee	$ 1,647.34	
Finance Committee	150.00	
Standards Committee	1,005.49	
Code Committee	30.00	
American Engineering Standards Committee	600.00	
Committee on Institute Development	71.00	
Annual Dues—International Electrotechnical Commission	250.00	
President's Special Appropriation	331.72	
Honorary Secretary	4,000.00	
John Fritz Medal Award	55.89	
European Standards Committees—Conferences	1,500.00	
Interest on United Engineering Society Building Addition Loan	556.95	
Miscellaneous Printing	252.73	
Membership Classification	771.75	
Amortization of Premium on City of Wilmington, Delaware, 4½% Bonds of 1934	52.14	11,275.01
Total		$125,985.98
Add:		
Increase in Accounts Payable—Subject to Approval by the Finance Committee, Expenses Undistributed at:		
May 1, 1918	$ 6,304.01	
April 30, 1919	6,362.87	58.86
Total Expenses		$126,044.84
Net Revenue		$ 8,899.48
Profit and Loss Credits:		
Proceeds from Sale of Old Electrotypes	$ 440.30	
Refund of Payment to Pan American Engineering Society	15.00	
Total		455.30
Gross Surplus for the Year		$ 9,354.78
Profit and Loss Charges:		
Uncollectible Dues Written Off	$ 1,985.00	
Dues of Members in Military Service and in Countries Affected by the War, Written Off	1,685.50	
Provision for Depreciation of Furniture and Fixtures	1,489.35	
Adjustment of Inventory of April 30, 1918, of Library Volumes and Fixtures	184.00	
Total		5,343.85
Net Surplus for the Year		$ 4,010.93
Surplus, May 1, 1918		579,405.62
Surplus, April 30, 1919		$583.416.55

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

STATEMENT OF CASH RECEIPTS AND DISBURSEMENTS FOR DESIGNATED PURPOSES, FOR THE YEAR ENDED APRIL 30, 1919.

EXHIBIT C.

RECEIPTS:	
Life Membership Fund	$216.68
International Electrical Congress of St. Louis Library Fund—Interest and Royalties	94.50
Mailloux Fund—Interest	45.00
Midwinter Convention Fund—Interest	6.54
Total	$362.72
DISBURSEMENTS:	
Life Membership Fund	216.68
Midwinter Convention Fund	34 23
Mailloux Fund	70.00
International Electrical Congress, San Francisco, 1915—refund of subscriptions	40.50
Total	$361.41

RECEIPTS AND DISBURSEMENTS PER MEMBER.

During each fiscal year for the past eight years.

Year ending April 30	**1912**	**1913**	**1914**	**1915**	**1916**	**1917**	**1918**	**1919**
Membership, April 30, each year	7459	7654	7876	8054	8212	8710	9282	10352
Receipts per Member	$13.19	$13.45	$14.08	$14.06	$13.62	$13.30	$13.17	13.05
Disbursements per Member	12.44	15.57	12.86	13.54	13.74	12.75	11.99	12.79
Credit Balance per Member	$ .75	*$2.12	$1.22	$ .52	*$ .12	$ .55	$1.18	$ .26

*Deficit.

Respectfully submitted for the Board of Directors,

F. L. HUTCHINSON, *Secretary.*

New York, May 16, 1919.

Presented at the 35th Annual Convention of
The American Institute of Electrical Engineers,
Lake Placid Club, N. Y., June 24, 1919.

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COOPERATION

PRESIDENT'S ADDRESS

BY C. A. ADAMS

INTRODUCTION

SINCE the last Annual Convention of this Institute the greatest war in the world's history has come to an end. Millions of lives have been sacrificed. Millions of men have been crippled in greater or less degree. Wealth to the extent of many billions of dollars has been destroyed. Most of the nations involved have been seriously impoverished. The whole social, economic and industrial order has received a severe shaking up and has in some countries been completely overturned. Widespread dissatisfaction with the old order prevails in nearly all of the countries involved in the war. Unrest is generally prevalent, and, however unreasonable the demands of the restless may seem, there probably *is* a reason. In any case "it is a condition not a theory that confronts us."

The old order has failed and can never wholly return. What will be the new order? What are we going to do about it? Are we as engineers, educated men, who pride ourselves on our breadth of vision, who complain because we are not properly recognized in large questions affecting the public welfare, going to crawl back into our little cabins and leave the steering of the ship to those we consider incompetent? Are we going to use our influence to keep the ship on the old course, in spite of the fact that it led to the rocks? Or are we going to ask the same question we ask when our engineering plans result in failure, namely, why? Are we going to scrutinize the ships' log to see why she ran on the rocks and then revise the sailing orders accordingly?

These are some of the questions, the consideration of which has urged me to deviate somewhat from the custom established by my predecessors, of discussing either Institute activities and policies or general engineering questions, in order to present a much broader question, of interest to us not only as engineers but also as citizens, a question which has repeatedly arisen in connection with my work for the Institute during the past two years.

Moreover this year the important question of Institute activities and policies is receiving a thorough discussion through our Development Committee before which we will all have an opportunity to express our views at this Convention.

The subject of *cooperation* to which I wish to call your attention has a decided bearing on several important Institute functions, and although it will be discussed largely in connection with these functions, it is the principle involved and its broad bearings on other questions as well, that I wish to emphasize.

My reason for selecting this subject is partly because of my recent experience in applying the principle, but more because the broad application of the principle seems to offer at least a partial answer to the questions propounded above, and also because this application is of peculiar interest to the engineer.

I am not proposing to cast aside the traditions of our fathers, nor the experience of the past, but rather to make use of that experience.

I do not propose any revolutionary program, but merely the hastening of the natural evolutionary development by the application of a little perspective and common sense. This does not involve altruism except insofar as a vision reaching somewhat beyond the end of ones nose may be considered altruistic. It is merely a step forward, a step of progress, which may prevent our being forced into some revolutionary stride which is doomed to failure and can mean only destruction and disaster as long as it endures.

COOPERATION IN GENERAL

The history of human society is the history of cooperation, at first between the individuals of a small group such as a family, then the cooperation of the small groups with each other to form a larger group such as a tribe, then of these larger groups to form a nation, then of several small nations into one larger nation, and now we are seriously considering a League of Nations.

The reason for these various increases in the size of the unit, is not an altruistic ideal, but the knowledge that each party to the cooperation will gain thereby, not only in strength, but also industrially and economically through a more extensive division of labor and an increase in the average productivity per unit of labor.

Every commercial transaction of the greatest or of the least magnitude, between individuals or groups of whatever size, is made on the assumption that it is profitable to both parties concerned, otherwise it would not ordinarily be made. Every such transaction involves a certain degree of cooperation, a certain degree of faith or confidence in each by the other. The more the mutual confidence and the cooperative spirit, the freer and the more efficient will be the interchange and the greater the mutual profit. This is merely the simplest possible illustration of cooperation to show its fundamental nature. Industrial cooperation from which my illustrations are drawn and with which engineers are mostly concerned, usually involves more than this simple and somewhat restricted cooperation between buyer and seller, it involves cooperation all along the line, internal and external, between producers, between consumers, and between producers *and* consumers.

The obstacles to cooperation, particularly between the larger units, are of two varieties, material, and human or intellectual. The chief material obstacles are space coupled with imperfect means of communication and transportation, differences in language, differences in coinage, weights and measures, and duties or tariffs. Some of these bear obviously only on international cooperation. The chief intellectual obstacles are tradition, custom, prejudice, suspicion, distrust, jealousy, narrow minded and short sighted selfishness or greed, or in general ignorance and lack of understanding one of the other. Most of this latter group bear upon minor or internal as well as upon international cooperation.

Most of the obstacles of both types may be looked upon as barriers which keep individuals or groups apart and thus prevent that mutual understanding which makes cooperation possible. It is my desire not only to point out the importance and value of cooperation, but also the part that we as engineers can play in helping to break down these barriers. My meaning can most easily be made clear by illustrations.

Standardization. Consider first the work of engineering and industrial standardization. The work of the Standard Committee of this Institute is second to none in its own particular field or in any other, either in this country or in any other country, in spite of the fact that the ground covered is a peculiarly difficult one. Why this success? Simply because of the *cooperative* spirit which has prevailed. Conflicting interests come together, pool their experience, share the work, place their cards on the table face up, and finally agree to abide by the resulting rules.

Does any one of these interests regret the results? Does any one feel that it has been a waste of time and money, that it has been chasing an illusory ideal, that it was visionary or impractical, that it was not a financially profitable investment in the long run?

But it is not only profitable to the producer, it is even a greater gain to the consumer by a reduction of cost, the elimination of at least some of the confusing and conflicting claims of competing salesmen, by rendering more definite the purchasers knowledge of the capacity of a machine of given rating and thus making possible a more suitable and accurate selection of a machine for a particular purpose. Thus it is an asset of no mean value to the industry and to the nation as well.

But this cooperative spirit does not always prevail, in fact rarely in the degree found in our Standards Committee. Until very recently the French National Committee of the International Electrotechnical Commission contained none of the designing or manufacturing engineers, it being assumed that the latter would be biased and partisan in their attitude. As a result the manufacturers formed a syndicate with a committee and standardization rules of its own, which were and even now are to some extent the rules generally employed in France although much inferior to our own. In some cases the American rules are specified. Even now the French rules originate in the Manufacturers Syndicate and are passed on to the French National Committee for their approval, with a consequent loss of time and efficiency.

As the work of our own Standards Committee expanded we found it overlapping the work of other Societies in adjacent fields, and cooperative relations were established. This failed from the lack of any suitable and generally acceptable cooperative machinery. A movement was then started by the Institute more than two years ago to organize a central body (the American Engineering Standards Committee) to coordinate all the work of engineering standardization being done by the various engineering organizations. The objects of this organization are to avoid overlapping, duplication of effort and the confusion of conflicting standards; to ensure the employment of an effective and sound procedure in the development of standards, to the end that a standard when promulgated may be not only workable but also acceptable to all concerned, and the only accepted standard of its kind; to stimulate desirable standardization and at the same time to shut off premature or ill-advised attempts at standardization.

The consummation of these objects will mean: an enormous saving of effort in the production of standards, a tremendous increase in the value and usefulness of standards, and, when the work is brought up to the needs of the time, an incalculable saving in the cost of production and the productivity of labor. International standardization will be a tremendous stimulus to foreign commerce; but such international standardization is in most cases exceedingly difficult without a central authoritative body with which similar foreign bodies may cooperate. Several instances of this difficulty which have actually arisen during the past two years could be cited, if time permitted. These have resulted in hopeless confusion, misunderstandings, and waste of time and money.

Great Britain has its Engineering Standards Association which, during its eighteen years of life, has demonstrated its reason for existence and its value to industry and to the Government. Its work in air craft standards alone, which it is doing on behalf of the Government, involves some fifty odd subcommittees.

France now has its Permanent Standards Commission a little more than a year old, and just getting under way.

Holland also has its Normalization Bureau for the same purpose, and Switzerland is just starting a movement in this direction.

With all these National Bodies our American Standards Committee has already established cordial cooperative relations.

The American Engineering Standards Committee, although organized last October is now in process of reorganization. But the success of any such movement is in direct proportion to the degree in which the cooperative spirit prevails, and the two years consumed before the first organization, and the present delay in the reorganization is due largely to some of the obstacles to cooperation mentioned in the second group above.

The conflict is chiefly and quite naturally between the desire to accomplish a highly desirable result and the desire on the part of each cooperating element to avoid paying the price, which may consist in a very slight loss in independence or prestige, although in the present case this will be negligible. It is the fear rather than the fact that causes the trouble. But even if the sacrifice were much more than it is, the price would be small in proportion to the result.

It is the generous cooperative spirit for which I am pleading, rather than the timid fearful spirit of him whose vision is of such short range that he dare not take a man's size step for fear of stubbing his toe, who holds the little present so close to his eye that it shuts out the whole landscape of the future, whose immediate self interest or small group interest is so dominant as to hide anything beyond.

Look around at the strikingly successful men of this country; rarely will you find one of the timid fearful type. He has vision even if sometimes of a very material nature; he sees a worthwhile goal some way ahead and starts for it; if he makes mistakes he tries again with added experience. The man who never makes a mistake never gets far. I am not advocating slap-dash methods, but rather more of the positive and less of the negative attitude, more constructive and less destructive criticism, more of the forward looking progressive spirit, and less of the visionless, timid, reactionary spirit.

To return for a moment to the American Engineering Standards Committee and its reorganization, may we not look to every member of this Institute to take part in a campaign of education and in the development of that wholehearted spirit of cooperation which will mean the support rather than the hindrance of many well meaning but timid objectors to this movement, which seems to promise so much in the development of our industries, in the increase in the productivity of labor, and in the breaking down of at least one of the barriers of international misunderstanding.

Research. Another fertile but as yet little cultivated field for cooperation is that of *industrial research.* Here we have a field where the obstacles of the second group are specially dominant, particularly short sighted self-interest and corporate interest, and the timid desire for secrecy.

That many of the most important and revolutionary developments of modern industry are dependent upon research needs no proof. It is not so obvious to many however that cooperation in industrial research is to any large extent feasible at the present time.

First let me point out that the line often drawn between scientific and industrial research is a very hazy one, namely between research the purpose of which is merely to extend the bonds of human knowledge and that intended primarily to meet an industrial need or to solve an industrial problem. In other words the difference is one of purpose rather than of method. But I think that, particularly since the war, most of our so called pure scientists have become greatly interested in the industrial value of their scientific work. Therefore when I speak of industrial research I include a very large part of the research work now being conducted in this country.

Consider for a moment the advantage of cooperative research Few individual corporations except the very large ones can afford either a suitable research laboratory or competent men to conduct the work. The result is that most of the research work is superficial and much of it misleading. The total cost is many times greater than of a comprehensive cooperative research led by the foremost experts in the particular field. Moreover some of the most vital and fundamental researches are either beyond the capacity of even the largest corporation laboratories or have to be postponed for those offering more chance of immediate returns.

I am fully aware of the difficulties arising from patentable developments, but these can readily be handled by suitable agreements between the parties to the cooperation.

After some experience in this field I am convinced that thorough going cooperation in industrial research would mean not only a reduction of the cost of research to a small fraction of its present figure, a much more rapid industrial development of the country as a whole and a material increase in the productivity of labor, but also an increase in the profits of every intelligent party to the cooperation.

Again I wish to point out that it is not so much a question of altruism as of a far sighted self-interest and patriotism.

Many other illustrations of cooperation in the engineering field could be cited, but those already briefly discussed will be sufficient for the present purpose.

Reverting now to the opening paragraphs of this address, let us consider some of the broader aspects of cooperation, particularly as they bear upon the great world problems which are insistent in their demand for solution.

Serious cooperation of any kind between widely separated groups is practically impossible without the mechanism of transportation and communication provided by the work of the engineer. Also with this mechanism developed even to its present degree of perfection, cooperation becomes not only possible but also desirable and necessary, even between comparatively widely separated groups. Moreover the problems which confront the world at this time are largely a direct result of this mechanism. Are we as engineers going to leave their solution to others? Are we going to be satisfied to play alone in our own little backyard and never look around us even after most of the fences have been removed by our own work. Are we going to fail to take an interest in our neighbor who has much that we need, from whom we have much to learn, and by cooperation with whom we can profit broadly? If we do offer cooperation is it to be with the provision that we gain all and sacrifice nothing? Are we going to be satisfied to sit back and criticize destructively the details of a cooperative agreement, priding ourselves on our critical faculty, however valuable that may be at times, when the real basis of the criticism is either intellectual pride or short sighted fear that we, as individuals or as a group, may lose a little of our independence or prestige; when the issue at stake is in some cases of such paramount importance (had we only the vision to see it) as to overshadow our very existence.

Let us rather make use of the logical habits of thought and freedom from bias which *should* at least be the result of our training, and take our part in the solution of the problems we have helped to create. Let us see the goal ahead and start for it without thought of fear or favor, as surefootedly as possible, but with that generous cooperative spirit which will surmount many an apparently impassible barrier, critical of details if so minded, but generously and constructively so.

Now just a word as to a specific and very serious problem, namely, that arising from the world-wide unrest in the labor group. That this condition exists must be admitted by the most optimistic. To ignore it is suicidal. It is difficult to characterise this condition in a few words as there are so many degrees of radicalism and of revolutionary spirit represented; but it may be safely stated then on the average, labor is unreasonable in its demands and seems to fail to realize that it cannot receive more wealth than it creates, or at best it has an exhorbitant idea as to the value of what it creates. For example in England labor is not only demanding higher wages but according to all reports is reducing the hourly output as well. There seems to be a prevailing notion in labor circles that the excess profits of the capitalist constitute a limitless supply which only needs the tapping; or to put it in another way, the labor group is trying to use its organized power as a monopoly, and to insist on "all the traffic will bear". The revolutionary element goes even farther.

It is very easy to criticise and condemn this attitude because of its unreasonableness, looking down from our superior height of intelligence. It is very easy to assume that it is merely a matter of showing the laborer the error of his ways and of forcing him into line. But would it not be wiser at this time to examine our own attitude with equal care, to make sure that we are setting an example which if followed by labor would solve the problem? Is demanding all the traffics will bear under the pressure of organized labor any worse than the same policy carried out by the capitalist whenever he has the monopoly grip. Unfortunately the two cases are not treated the same by our laws; labor monopoly is not subject to the same limitations and responsibilities as is capital monopoly; that disparity should be removed. But there are two forms of monopoly other than of labor which are not only not limited by but are actually fostered and protected by our laws, and in which the only limitation ever dreamed of by the owner is, "all the traffic will bear"—These are patents and titles to land.

Our patent system has a worthy motive, but who will claim that the commercial value of a patent bears any relation to the brains, industry and expenditure that entered into its development, or that in general the patent system works for justice to all those who share in the development of a patent. It is often a matter of pure accident as to which of two men who have conceived the same idea at about the same time reaps the reward, and it often goes to the less worthy. Often the *originator* of *an idea* makes a much less important contribution than the man who makes it a commercial product. But to point out the defects and the injustices of our patent system would take all day. This is another realm in which broad-gage cooperation would eliminate much of the unfair and gambling aspects of the patent system, and distribute the rewards in a much more equitable fashion.

Of all sources of monopoly our present land system is the most unfair, the most dangerous, the most far reaching in its influence. Under it a land owner is paid a premium for holding valuable land idle, for forcing a community to spend its money to build around his land and to take its time to travel around or past his land. The sight (or unimproved) value of land in this country constitutes about one-half of our national wealth, yet the landowning class as a group taken from the beginning of the settlement of the country, have been made a free gift of that wealth, which is the product of the industry of society as a whole. This is a statement which cannot be controverted.

Private ownership of land seems to me desirable, it has a wholesome stabilizing influence, and the injustice of our present system can be largely removed without sacrificing any of the real advantages of private ownership, by shifting taxation from individually created wealth to community created wealth which is the sight value of land *i. e.* by taking for the community what the community creates and leaving to the individual what he creates, by shifting taxation from industry to privilege. But this is a long story by itself and I touch upon it at this time only as one of a group of suggestions as to possible ways in which we can assist in progressive rational *evolution* of society rather than encouraging and inducing a *revolution* by a reactionary policy. I assure you that none of these suggestions can be called other than conservative at this time.

Are we sincere in our desire to be more recognized in our broader capacity as citizens and to be consulted in matters of broad public interest; if we are not sufficiently interested in those matters to make an intelligent study of them; if we are satisfied to accept without analysis the prejudices and propaganda of a biased group, however intellectually superior that group may consider itself; if we cease to utilize our logical habits of thought, our habit of analysis, of demanding the reason why, as soon as we step outside of the realm of those physical laws which force us to think straight? Are there no laws in this other realm of human relations which are just as inexorable as the physical laws with which we are so familiar? Is there no law of compensation which is the counterpart of our law of conservation of energy? Are we going to be allowed to go unpunished for crooked or careless thinking in this other realm any more than in the purely physical realm?

What can we expect of labor in the way of intelligent fairmindedness if we, with our superior advantages encourage the perpetuation of institutions which work for serious injustice to the many for the benefit of the few, or even if we allow them to persist because of our lack of intelligent fairmindedness.

My opinion as to the seriousness of the present world situation, as to the importance of the problem before us, is not mine alone but that of many thinking men in this country and in others. I have talked with many influential men in France and England and have found a striking unanimity on this point.

May we not as engineers utilize our training and experience, our method of thought of which we are so proud, to encourage clean, straight, unbiased and fairminded thinking, and to encourage that broad generous cooperative spirit which will mean so much in breaking down the barriers which separate classes within a nation, as well as the nations themselves, and which is essential to the solution of the world problem which is knocking so hard at our door?

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THE ABSOLUTE MEASUREMENT OF THE INTENSITY OF SOUND

BY ARTHUR GORDON WEBSTER

ABSTRACT OF PAPER

This paper includes a description of a series of acoustical researches extending over a period of twenty-eight years. The properties of vibrating bodies and the subject of elastic hysteresis are discussed. Two fundamentally important instruments for the absolute measurement of sound have been developed and the theory given. The first is the standard of sound, called the phone, which is capable of reproducing at any time a sound of the simplest character and which permits the output of sound to be measured in watts of energy. The second is an instrument called the phonometer for measuring a sound in absolute measure. This instrument is now practically as sensitive as the human ear. Two essential features are the small damping of the vibrating system which results in extreme sensitiveness, but at the same time in great selectiveness, and the capacity for being tuned. Each of these instruments is fitted with a variable volume resonator and tuning over a range of about two octaves is accomplished by varying the volume of the resonator and by changing the tension of the wires to which the piston is attached. The determination of the space distribution of sound and of the effect of disturbing bodies, and the measurement of the reflecting coefficient of surfaces have been accomplished. The phonotrope is a third instrument designed and used to find the direction of a source of sound, for example a fog signal.

THE profession of acoustical engineering is a new one that has arisen during the last few years. The late Professor Wallace C. Sabine, of Harvard University, attracted the attention of the public to the very great importance of physical measurement and thoroughly scientific design in the construction of auditoriums which until his time had remained an entire mystery to architects.

The writer has been interested for many years in the problem of the measurement of sound in absolute units, involving the design of an instrument which is capable of determining, at any point in space, the pressure in the air wave as a function of the time. In order to carry out this object three things are necessary.

First, the construction of a standard of sound which will enable a given sound of the simplest possible character, namely, that in which the pressure varies as a simple harmonic function of the time, to be reproduced at any time, and which permits an output of sound to be measured in watts of energy. This problem has been solved by a number of persons including Professor Ernst Mach and Dr. A. Zernov of Petrograd.

Second, the invention of an instrument capable of measuring a sound of the simple harmonic character described, also in absolute measure; that is to say, in such a way that the amplitude of pressure variation may be measured in absolute measure, as dynes per square centimeter, or in millionths of an atmosphere. This problem has also been successfully traeted by a number of investigators, among whom may be mentioned Professor Max Wein, Lord Rayleigh and Lebedeff.

Third, a step in the process remains which is perhaps equally important as the first and second. Given the invention of the proper source of sound, which I have denoted a phone, because it is a sound and nothing else, and a proper measuring instrument, which I call a phonometer, there still remains the question of the propagation and the distribution of sound in space between the phone and the phonometer. Any measurements made in an enclosed space will be influenced by the reflection from the walls, and even if we had a room of perfectly simple geometrical form and were able to make the instruments of emission and reception work automatically without the disturbing presence of an observer, it would still be impossible to specify the reflecting power of the walls without a very great amount of experimentation and complicated theory. Nevertheless, this is exactly what Sabine did. He did it, however, by employing as a receiving instrument the human ear. Those who have made experiments upon the sensitiveness of the human ear for a standard sound will immediately doubt the possibility of making precise measurements by the same ear at different times, and particularly of comparing the measurements made by one ear with those made by another. Nevertheless, Sabine attained wonderful success and was able to impart his method to pupils and colleagues who carried on his methods successfully.

To proceed with the question of disturbing objects, one should take his phone and his phonometer to an infinite distance from all objects, which is manifestly impossible. The plan which I followed was to attempt to get rid of all objects except an infinite space covered with a surface the reflecting coefficient of which could be measured. I found the proper weather and the proper space on the golf links of a country club where conditions appeared to be favorable. Several days were spent in determining the reflection coefficient. This was done about ten years ago, whereas with the instrument available to-day it could be done in a very few minutes.

The history of my investigations is briefly as follows: In 1890 I proposed to use a diaphragm made of paper or some similar substance which should be placed, shielded on one side, at the spot where the sound was to be measured. Upon the center of the diaphragm was cemented a small plane mirror. In close juxtaposition and parallel with this was the plane side of a plano-convex lens which viewed in the light from a sodium flame was to give Newton's rings, or as we now call them, interference fringes. Of course, when the sound falls upon the diaphragm, the fringes vibrate rapidly and disappear from sight. I then determined to use the stroboscopic arrangment which would permit the viewing of the fringes as they slowly shifted their position. All sorts of difficulties occurred. The light from the sodium flame was not strong enough to permit the fringes to be seen through the stroboscopic device. It was not at that time easy or perhaps possible to make an electric motor that would drive a stroboscopic disk at a constant speed. One of the first difficulties was to devise a method of controlling a synchronous motor. This was accomplished by means of interrupting the current by a tuning fork.

Later I made the acquaintance of Professor A. A. Michelson and of his remarkable optical interferometer, and I immediately saw that one of the difficulties which I had met, namely, the difficulty of adjustment of the lens so that it should not strike the vibrating plate, could be overcome at once, as the two mirrors in the Michelson interferometer could be any distance apart. Also the trouble due to the faintness of the light disappeared, for in Michelson's instrument white light could be used, and it was possible to use gas, incandescent or arc light with good effect.

In 1896 I put the subject in the hands of a student who produced an instrument which was successful. The examination of the substance suitable for a membrane or a diaphragm consumed much time, and all organic substances such as parchment, paper or anything of that sort had to be discarded because it was impossible to keep the tension constant under the changes of moisture in the air. Metal was found to be quite out of the question on account of the difficulties due to thermal expansion. We next decided upon thin glass diaphragms which we afterward found were used by phonograph companies. A slight change of temperature, however, such as was made by breathing upon the diaphragm, would sometimes produce a change of pitch of several tones, so I next decided to clamp the glass diaphragm upon a ring sawed out of plate glass and cement it on with silicate of soda. I finally found that it was possible to get mica so flat that it was superior to the best possible glass, and this gave me the best results up to that time.

Let me now state briefly the qualities which the diaphragm must have in order to be successful. It is well known to physicists that a flat diaphragm can vibrate in an infinite number of modes which the physicist calls normal vibrations. In the simplest mode the diaphragm vibrates so that every point moves in the same direction. The natural period of this vibration is the lowest that the diaphragm can have. Next is a mode in which the central portions of the membrane move in one direction while all those outside of a certain circle, which we call a nodal line, move in the opposite direction. Other vibrations have radial, as well as circular, nodal lines on the opposite sides of which the diaphragm is moving in opposite directions. When a mass is screwed to any point of the diaphragm its motion is entirely changed. And any apparatus that may be attached to the diaphragm and required to do work, such as the carbon button of the telephone, or anything that interferes with the free response of the diaphragm to the variations of the air pressure will alter the action in such a way as to make it extremely difficult of interpretation. My idea, then, was to make a diaphragm which did not do any work at all, but merely carried the mirror which moved practically by itself.

Now, in spite of the great variety of forms and vibrations, it can easily be shown that under proper circumstances the diaphragm will move essentially as a whole, and may, therefore, be compared to a single body which has three characteristic constants: First, its mass; second, its stiffness, defined as the force required to produce a unit deflection of its nodal point; and third, and most difficult to control, the coefficient of damping, which is defined as the force of resistance that will be exerted from any cause when the velocity of the body or the nodal point of the diaphragm is unity. This damping must be due to a large number of causes. In the first place, the resistance of the air will cause damping. In the second place the energy of the sound waves that are radiated from the vibrating diaphragm will cause damping. In the third place and by far the most important, the bending of any body is resisted by elastic forces and we therefore have the phenomenon of elastic fatigue. In order to settle the question "what is the best material from which to make tuning forks", which has been variously answered as tool steel, bronze, bell metal, quartz, etc. I perceived that it was necessary to have an exact method of experimentation.

In striking a steel bar supported by a string at two points it will be observed that the high overtones emitted by the bar rapidly die away, and it occurred to me that if the bar was thrown into one normal vibration there would be a bar rate of damping for every normal vibration, and that by stating the rate of natural damping a natural hysteresis could be studied. This was demonstrated experimentally by my assistant Mr. James L. Porter with very successful results as far as the experiment went. The mathematical theory has been lacking up to the present time. Two theories are possible, first the theory of solid viscosity, and second the theory of heredity, or elastic hysteresis. The attempts to compute the results of our experimental measurements are now approaching completion, and we soon shall be able to give a theory of elastic hysteresis. My conclusion is that quartz is the best substance from which to make tuning forks.

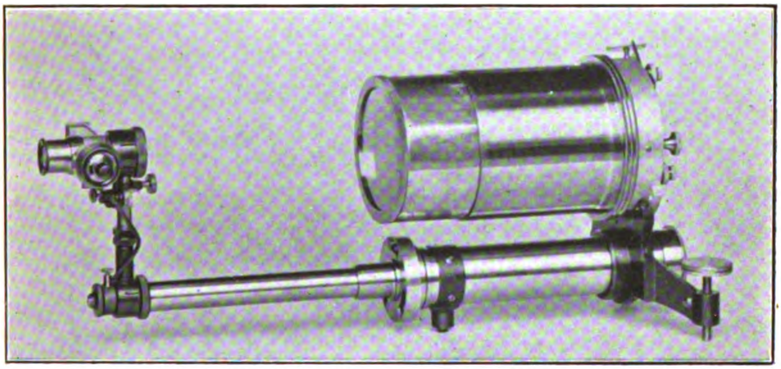
This digression from the investigation is told in order to show the very great difficulties that this subject presented.

The illustrations herewith show the apparatus as it was built several years ago. It was mounted upon a heavy stand made of bronze, covered in at the back by a heavy bronze cover, through which protruded through air-tight fittings the shafts turning the screws of the interferometer adjustments, three in number. Upon the front of the instrument was attached a resonator properly tuned and at the side was a small incandescent lamp with a straight filament arranged horizontally, an image of which was projected by a lens upon the first miror of the interferometer. A telescope was focused upon this image, giving an image in the reticle of the horizontal straight filament. This was crossed by the vertical interference fringes. The objective of the telescope was carried by one prong of a tuning fork which oscillated vertically and this, combined with the horizontal oscillation of the fringes due to the vibration of the diaphragm, resulted in a figure in the form of an ellipse. On tuning the two sounds together this ellipse could be caused to go through its various phases as slowly as desired. At the moment when the ellipse degenerated into an inclined straight line the reticle, which was tilted by an observer, was brought into line with the interference lamp and the tangent of the angle was read off on a tangent scale. The pressure on the sound wave was then proportional to the number read off on the tangent scale. The apparatus was used in this form for a good many years, a precursor of it being shown at the Congress of Physics at Paris in 1900.

Professor D. C. Miller's phonodeik which is a very beautiful instrument, was designed for quite other purposes than the phonometer of the speaker. It was intended to photograph sound curves of any sort and by means of it Professor Miller has obtained most beautiful reproductions of speech, and sounds of musical instruments. Unfortunately, this instrument does not adapt itself in the least to absolute measurements. One objection to Professor Miller's instrument is that it employs a spring made of rubber material. This spring has to be calibrated whenever measurements are taken, and it is well known that the properties of soft rubber are far from constant.

The speaker next undertook to devise a better mode of reading the amplitude of vibration of his diaphragm. In the first place, the mirror which was carried by the diaphragm in Professor Miller's apparatus, instead of being carried on an axis in jewels was placed on a thin steel torsion strip which could be made at far less expense and could be rapidly adjusted. The straight filament lamp was now viewed through a telescope into which the mirror focused the filament in the reticle of the eyepiece. A magnification of about 1200 to 1500 is used. The instrument was also used photographically just as the old instrument had been used to photograph the motion of the interference fringes. Photographing moving interference fringes, however, was attended by many experimental difficulties.

A new instrument in the form described was made for Professor Louis Vessot King, of McGill University, who had



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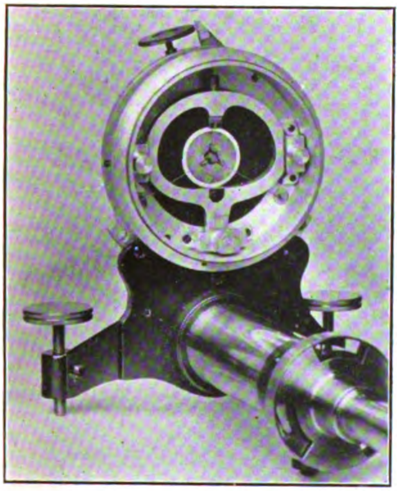

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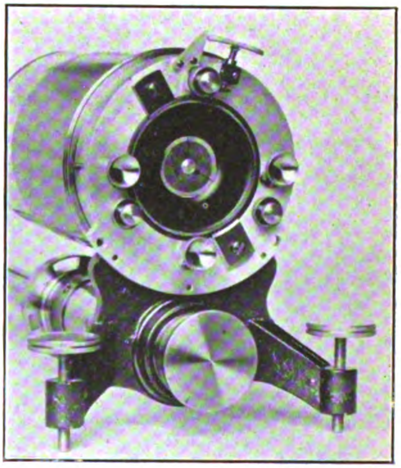

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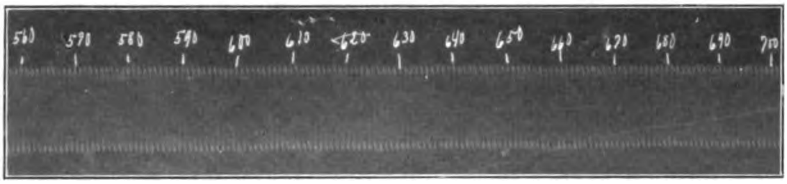
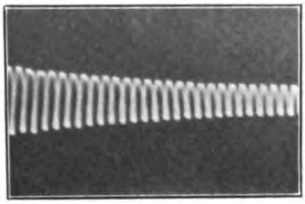
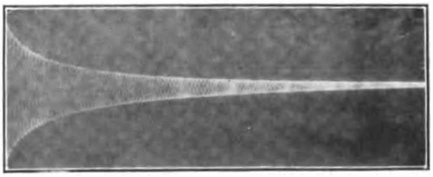
PHONOMETER—FRONT VIEW



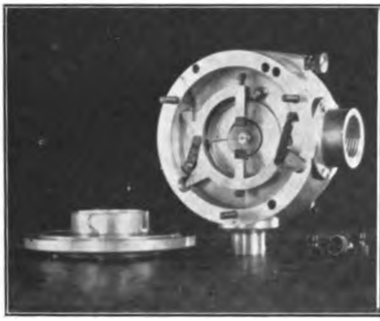
QUARTZ TUNING FORK



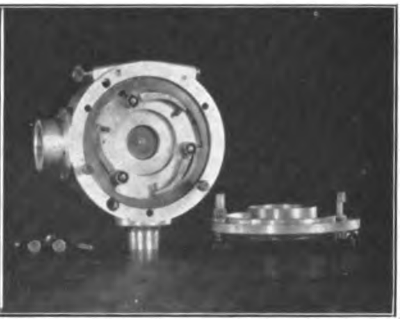
DAMPING OF QUARTZ TUBE



DAMPING OF PHONOMETER



PHONOTROPE



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PHONOTROPE—TUNING DEVICE

a commission from the Canadian Government to make experiments upon fog signals and had secured permission to investigate the great siren at Father Point on the St. Lawrence. Professor King spent the whole summer at Father Point in making the first survey of an acoustical field ever made. The Canadian Government had furnished him a large steamer with which he went out every day, blew the "criard" as the natives call it, the very perfect siren which can be heard thirty miles away in good weather, and explored the gradient of sound under all meterological conditions, studying the wind, the temperature, and the temperature of the water, etc. This spurred the speaker on to undertaking the same thing in this country. It was impossible to get from the Lighthouse Board the loan of a steamer, but permission was given to go on any lighthouse steamer going along the coast of Maine. The first step was to tune the phonometer for the different pitches, and at that time the only method of tuning the diaphragm was to load upon it small pieces of wax. This, although it worked perfectly, seemed very clumsy, and not an engineering method. It was therefore decided to redesign the whole instrument so that it could be tuned continuously. It occurred to me that this could be accomplished by furnishing potential energy to the diaphragm by means of a spring parallel to it, and bearing against it by means of a bridge, and tunable like a violin string. The very first attempt showed this to be entirely successful. Then the idea immediately presented itself that if a string could be tuned continuously why use the energy of bending at all and why not get entirely rid of all difficulties of elastic fatigue. Since that time the diaphragm has been entirely discarded and replaced by a stiff disk supported upon three strings in tension. The disk is made of aluminum or mica and is carried by a little spider made of aluminum containing three clamps to hold the wire. The wire is made of steel and is under tension about steel pegs, two of which are turned roughly by means of a screw driver, the other by means of a lever actuated by a micrometer screw. We have now a very perfect instrument at least ten times as good as the one Professor King had.

A few figures will show the advantages in the reduction of the damping. In a system of one degree of freedom the amplitude of the vibration for the most perfect tuning is inversely proportional to the quotient of the damping coefficient k

divided by the mass m. When we began with the good glass diaphragm we had a value of k something like 150. In 1913 the mica diaphragm lent to King had reduced this to 30. With the phonometer as built now we have reduced this to 1.34. In all these cases the mass was about the same so that so far as the sensitiveness goes, the instrument is more than one hundred times as good as it was ten years ago. The instrument now competes in sensitiveness with the human ear and may be tuned to pitches varying by perhaps two octaves. If I strike a tuning fork and allow its amplitude to die away, a person looking into the eye-piece of the instrument cannot say with certainty whether he can see the sound or hear it the longest. Unfortunately, however, this very great sensitiveness obtained by a small damping is attended with a very great disadvantage. The instrument is extremely selective and if the tuning varies by a very small amount the amplitude falls off very greatly.

Within the last three months I have devised a plan of doing away with this, and making an artifcial ear. For, as you know, the human ear has a wonderful sensitiveness, not for all sounds, but to sounds of a frequency of perhaps 30 per second up to perhaps 30,000 per second, attaining a maximum sensitiveness for frequencies of from 1000 to 1500. We know how this affects the telephone and how the damping of the telephone and microphone disks enables the response to be carried over a large range, so that they answer very well for the frequencies involved in speech. Nevertheless, the sounds of *s*, *f*, *t*, and certain others, on account of the very high harmonics involved, are most difficult to transmit telephonically.

Having described the construction of the diaphragm, the new piston with wires, and the method of reading the vibration by means of the inclined mirror which is also reduced to absolute measure by means of the interferometer temporarily attached, or more simply by displacing the diaphragm by a micrometer screw, I come to the theory of the instrument. The resonator into which the air enters, and the hole which is now constituted by an angular opening around the disk, furnishes through the movement of the air in and out an additional degree of freedom. We are then in the possession of a system with two degrees of freedom, statically coupled by means of the increased pressure in the resonator when the piston is forced in. The theory of such a system under the action of the periodic force is well known and has been treated by Professor Max Wien in great detail. If the frequency in 2 π seconds be n and if the mass be m, I shall call the stiffness minus the product of the mass and square of the frequency the uncompensated stiffness or mistuning. If this were equal to zero for a system of one degree of freedom we should have resonance. In the case of two degrees of freedom I plot the mistunings horizontally and vertically, and the amplitude of response as a third co-ordinate. I thus get a surface that may be described as two mountain peaks with a pass between them, the summit of the pass being when both mistunings are zero; but this is by no means the highest point of the region. To attain either summit we must mistune both systems by a certain amount which is porportional to their two dampings. The addition of the resonator to this instrument may produce an increase of sensitiveness of fifty times. You now see, I hope, how we have obtained an engineering instrument, everything in which is measurable in absolute measure. It is obvious that the piston may be made the diaphragm of the telephone, that the instrument may be used by the psychologist, the engineer, the physiologist, for instance in a stethoscope, and in many other applications.

I turn now to the source of the sound, the phone. With the advent of the tuneable diaphragm came the new phone. It is very light. The amplitude of the diaphragm is measured by a microscope. I use a hot wire vacuum tube as a source of alternating current, tuneable at will, and tune the phone to it. We thus have in small compass a very perfect set of acoustical instruments.

The third portion of my investigations involved a determination of the coefficient of reflection of the ground. In order to accomplish this the phone is set at a convenient height and the phonometer at a convenient distance. The latter is then moved back and forth at the same height, when it is immediately found that interference between the phone and its image in the ground sets in, producing a variation of the intensity of the sound. Different curves have been plotted for different coefficients of reflection. When the reflection is zero or the ground is acoustically perfectly black we have a rectangular hyperbola. The existence of the minimum is obvious to the most unskilled observer. We found the coefficient of reflection of grass, or gravel surface, to be about 95 per cent. I may say that the whole measurement of the instruments of the two ends and the transmission between checks up with an accuracy of probably better than two per cent. With this apparatus all sorts of experiments have been performed. By attaching to the phonometer a long glass tube or antenna it has been made possible to explore all sorts of places, such as the field within a horn or a tube lined with absorbent substance. The theory has been always completely verified. In order to examine the transmission of sound a piece of substance is clamped between two heavy cast iron rings cemented against a hole in a brick wall which will exclude all sound except that that comes through the fabric. The transmission through doors, windows, walls, and telephone booths may be carried out very quickly, and the coefficients of absorption and reflection determined.

Finally, there has resulted an instrument for determining the direction of a fog signal blowing in the fog which I call a phonotrope; since the heliotrope turns toward the sun, the radiant of heat, so the phonotrope turns toward the radiant of sound. This instrument consists of two equal horns bringing the sound to the opposite side of the same disk. It is arranged to be rapidly tuned to the whistle, and when the whistle blows the band of light spreads out; the whole instrument is then revolved until the band reduces its width to zero when the whistle is directly ahead. This instrument was taken to Pensacola to see whether it would determine the direction of an aeroplane in the night. It was found to be as sensitive as the ear, but owing to Doppler's principle, the continual coming and going of the aeroplane changed the pitch so as to put it out of tune. A new modification that I have devised will obviate this I hope.

I have now given you briefly and without any mathematics an account of the principles which I think must always be involved in any measurements of sound. I have always been very anxious to join forces with Professor Miller and to calibrate his instruments so as to render his wonderful results of serious interest to the physicist. I am also glad to co-operate with all my colleagues whether engineers, physicists, physiologists or physicians. It will be a great pleasure to me to know that this apparatus may be of use in solving any of the multitude of questions that confront us.

PAPERS ON SOUND

1. B. A. A. S. Toronto, Aug. 1897. "A New Instrument for Measuring the Intensity of Sound".
2. A. A. A. S. Boston, Aug. 1898. "A New Instrument for the Measurement of the Intensity of Sound".
3. A. A. A. S. Washington, Jan. 1903. "A Portable Apparatus for the Measurement of Sound".
4. American Phys. Soc., New York, April 1902. "An Apparatus for the Quantittive Study of Sound."
5. Am. Phys. Soc., New York, April 1902. "Vibrations of Rotating Wires, Spindles and Shafting."
6. Nat. Acad. Sciences, Boston, Nov. 1906. "Acoustic Measurements".
7. Nat. Acad. Sci., New York, Nov. 1907. "Rayleigh's Disc as an Absolute Measure of Sound".
8. Am. Acad. Arts & Sci., Boston, May 1908. "Absolute Measurements of Sound".
9. Am. Phys. Soc., New York, Oct. 1908. "Distribution of Sound from the Megaphone".
10. National Acad. Sci., Washington, April 1910. "On the Distribution of Sound from the Megaphone or Speaking Trumpet".
11. Nat. Acad. Sci., Washington, April 1910. "A New Method for the Study of Elastic Hysteresis."
12. B. A. A. S., Sheffield, Aug. 1910. "A Complete Apparatus for the Measurement of Sound".
13. Am. Phys. Soc., Washington, Dec. 1911. "Elastic Hysteresis in Metal Bars".
14. Am. Phys. Soc., Washington, Dec. 1911. "Another Instrument for Photographing Sound".
15. Am. Acad. Arts & Sciences, Dec. 1910. "The Wave Potential of a Circular Line of Sources".
16. Am. Math. Soc., Poughkeepsie, Sept. 1911. "The Wave Potential of a Circular Line of Sources".
17. Am. Phys. Soc., Cleveland, Jan. 1913. "Some Points Concerning Absolute Measurements in Sound".
18. Am. Phys. Soc., New Haven, March 1913. "Forced Vibration of a Circular Plate".
19. Nat. Acad. Sci., Baltimore, Nov. 1913. "A New Portable Phonometer".
20. Nat. Acad. Aci., Baltimore, Nov. 1913. "The Transmission of Sound Through Porous Materials".
21. Am. Phil. Soc., Philadelphia, April 1913. "Some Observations of the Transmission of Sound Through Walls."
22. Am. Physical Soc., Washington, April 1914. "A New Phonometer".
23. Am. Phys. Soc., Philadelphia, Dec. 1914. "A New Standard Phone and Phonometer for any Pitch".
24. Nat. Acad. Sci., New York, Nov. 1915. "Experiments and Theory of Conical Horns".
25. Nat. Acad. Sci., New York, Nov. 1915. "Instruments for the Measurement of Sound".

26. Nat. Acad. Sci., New York, Nov. 1915. "An Instrument for Finding the Direction of a Fog-Signal".

27. Am. Phys. Soc., Columbus, Dec. 1915. "Mechanical and Acoustical Impedance, and the Theory of the Phonograph".

28. Am. Phys. Soc., Columbus, 1915. "Impedance of Conical Horns".

29. Am. Phys. Soc., Columbus, Dec. 1915. "The Phonotrope, a new Instrument for Finding the Direction of an Acoustical Ray".

30. Am. Math. Soc., Cambridge, Sept. 1916. "On Acoustical Impedance, and a Theory of Horns".

31. Acad. Sci., Boston, Nov. 1916. "Practical Tests of a New Phonotrope".

32. Nat. Acad. Sci., Baltimore, Nov. 1918. "An Automatically Played Brass Instrument".

33. Am. Phys. Soc., Baltimore, Dec. 1918. "A Mechanically Blown Wind Instrument".

ANNUAL REPORTS OF TECHNICAL COMMITTEES

ANNUAL REPORT OF THE POWER STATIONS COMMITTEE

To the Board of Directors,

IN answer to the request of the Board's Committee on Technical Activities that suggestions be offered for improving the technical work of the Institute, we incorporate our suggestions in this Committee's report for the year 1918-1919:

(A) AS TO PLAN OF WORKING OF TECHNICAL COMMITTEES

Can improvements be made in the co-ordination of the work of the authors of Institute papers and that of the Technical Committees?

In the past the great majority of papers in our PROCEEDINGS were secured either from direct offers of authors or through the solicitation of Committees.

Lately it has been the custom to refer every paper, before acceptance, to the Meetings and Papers Committee, which practically consists of a Chairman and a Secretary, with the Chairmen of the Technical Committees as members. Unsolicited papers are referred by the Meetings and Papers Committee to one of its members for endorsement or criticism, the member to report being the Chairman of the Technical Committee most interested in the subject of the paper in question. Papers solicited by a Technical Committee are accepted upon the recommendation of its Chairman, without previous submission to the members of his Committee, except by title.

In practically all cases, therefore, papers are not submitted and discussed by any Committee in advance of presentation before the Institute.

Hence, in the past, with few exceptions, the main work of the Technical Committees has been confined to secure especially qualified authors to write papers on subjects in which the Committee was interested. While the papers are nominally submitted under the auspices of this or that Committee, in fact the Committee itself never has an opportunity of acquainting itself with them. It follows that the discussion in the open meetings is greatly made up by comments and criticisms of

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NOTE:—No reports made by Traction and Transportation Committee and Electrical Machinery Committee.

members of the same Committee under whose auspices the paper is presented.

The suggestion arises: *Could not material advantages be secured by the Committee discussing the paper before it is presented at the general meeting of the Institute?*

In fact, should not the Committee share in the responsibility with the author or write, as an introduction, a brief statement of the opinions and conclusions of the Committee, either endorsing the author's paper in full or qualifying any point of divergence, giving its reasons and evidence to the contrary views?

If this course were followed, the papers and the discussions would improve, because the author would gladly revise, condense or modify his draft, if that would make his paper more clear and complete, eliminating small inaccuracies, superflous matter or statements susceptible to misconstruction, and adding information of value to corroborate the conclusions.

Also when views fundamentally and radically at variance are prevailing on a given subject, the Committee should secure different papers, carefully discussed and prepared to convey comprehensive, clear and substantiated statements of the facts from the different angles.

The suggestion is not to curtail the freedom of the writers, but only to assist them with whatever constructive criticism the Committee can give.

The result would be that the Institute PROCEEDINGS would become more condensed, valuable and readable than under the present method, and the importance of the Committee's work immeasurably enhanced.

The suggestion is in the direction of creating an organic administration of the technical work of the Institute, which will automatically expand to reach out for, and divulge in crystallized form, the information and experience of more and more members. This work would grow and widen from year to year along lines of greater benefit to, and closer co-operation with, each member of the Institute.

In the interest of effectiveness, this suggestion possibly would displace the newly organized Committee on Technical Activities. The respective Chairmen of Technical Committees as members of the Meetings and Papers Committee should, through its Chairman or individually, report to the Board of Directors in matters pertaining to papers, reports, co-operation with sister societies or institutions, etc.

(B) AS TO SUBSTANCE OF STUDIES OF COMMITTEES WITH SPECIAL REFERENCE TO THE POWER STATIONS COMMITTEE

There exists considerable indefiniteness as to what field a Committee, like the Power Stations, should cover. A power station presents a great complexity of features, like those of design, mechanical and electrical equipment, operation, efficiency of generation, production costs, etc. Many of these subjects, for instance, are strictly mechanical, though perhaps of preeminent importance only in electrical power stations.

Take, as an illustration, the steam turbine. Its design and construction are carried out by mechanical engineers and frequently discussed by the Society of Mechanical Engineers. Similarly, the features of operation, efficiency of generation, and production costs are mainly objects of study by committees of associations of operating companies most vitally interested in the subject. Features of design of electrical apparatus would, under the present organization of committees, come under the jurisdiction of specific committees, like Electrical Machinery, Measuring Instruments, Protective Devices.

Without extending further this analysis, one readily sees that, if we are bound too closely by these limits of existing specialization, we lose the opportunity of doing constructive work in a broad sense. We must, therefore, overlap in other fields under the limitation of not conflicting with other activities in so far as our work would be mere duplication of efforts already satisfactorily covered by others.

To illustrate this principle, let us outline one of the studies which this Committee has had under consideration for the last two years and which will shortly be presented to the Institute. The subject is "Limits of speed and power of single-shaft steam turbo generator units." Three papers are being prepared, two covering the steam end and one the electrical end. It is hoped that these papers will give an idea of limits of power and efficiencies of machines of existing types, *i.e.* a single-shaft steam turbine or a single-shaft generator for steam turbines. Since the study was first considered, its realization having been retarded by the war, there occurred three or four serious mechanical failures of steam turbine wheels which have created considerable concern to the users and aroused a widespread interest in one phase of this theoretical subject. The details of such occurrences can, for obvious reasons, only be discussed by the manufacturers and the users. This has been done but, to a large extent, the findings are properly considered confidential matters, often having a legal aspect, which cannot be made a subject of investigation and report by this Committee. One the other hand, the users would greatly benefit by any work of this Committee that, regardless of specific experiences, would outline the possibilities and limitations of power capacity of single-shaft turbo generators for different speeds permissible by the given frequency. The erroneous remark is often heard that it is unsafe to go beyond a certain limit in the capacity of units for central stations. In reality, units of twice or three times the power of the largest existing units can be manufactured to have the same or even greater factor of safety. Possibly such units may be more costly, or less efficient, or too heavy, or of too large dimensions, or be undesirable in situations where they would concentrate all the power of a station in two or three units instead of five or six or more, but we should not dismiss the study of the possibility of such machines simply from the wrong assumption that they cannot be made as safe as smaller capacity units, because in some situations the larger units may yet prove to be of advantage.

In any event, if they are undesirable, we should know why they are so. The papers under preparation will discuss these features and the Committee believes that such study will be of benefit to manufacturers and users if the study is intelligently carried out.

As we stated before, this departure of invading some of the fields of other technical societies or associations must be done with the understanding that the Committee will not attempt to duplicate the work of others, like, for instance, the Prime Movers Committee of the N. E. L. A. The latter, as a committee of an industry, can obviously fully investigate every operating feature or defect of apparatus and secure information to which this Committee cannot properly have access. On the other hand, features of engineering and design of machines can only constructively be discussed with the co-operation of users and the principal assistance of engineers thoroughly familiar with calculation and design of machinery.

It would appear to us, therefore, that there is a clear line of demarcation for the field of activities of this Committee, which, if directed along the plan first suggested, offers the promise of giving material aid to all the interests concerned.

From this illustration we submit that, as to substance, the work of the Committees must in certain cases be broadened even to the extent, sometimes, of invading the field of other technical societies or committees of the Institute where this is necessary to make a comprehensive study of the subject, under the condition of not duplicating work already satisfactorily and more properly done by others.

(C) PROGRAM OF FUTURE ACTIVITIES

Other proposed work of this Committee for the ensuing year consists of:

A paper outlining the statistical items which are essential in reporting efficiencies of power plants—this to the end of standardizing and making possible comparisons between different plants, which are not possible at present on the basis of the information given in all the published reports of United States Bureaus, State Commissions or other Governmental bodies.

A comprehensive review of the relative merits of shunt and compound wound exciters, steam and motor driven exciters, etc. has been considered and is recommended for the incoming Committee.

While the war continued it was found impracticable to make progress along the study of a national policy for the generation and utilization of power, as referred to in last year's report, but some of the members have further studied and investigated the broad subject and will submit suggestions and recommendations to the Committee or the Board as soon as practicable.

PHILIP TORCHIO, *Chairman*

ANNUAL REPORT OF THE TRANSMISSION AND DISTRIBUTION COMMITTEE

To the Board of Directors,

THE Committee on Transmission and Distribution submits the following report for the year 1918–1919:

The need for further reducing the membership of the Committee, as pointed out by the preceding chairman was again brought out very forcibly during the past year.

The large and scattered membership made it impossible to call meetings and it was found necessary to conduct the work entirely by correspondence. This method is generally unsatisfactory, but was particularly so in this case because many of those appointed seemed to consider their connection with the Committee as purely honorary, involving no obligation on their part to enter actively into the work. Several of the members made no reply to any of the communications sent out during the year.

The number of papers presented during 1918–1919 was somewhat smaller than usual because activity during the war period was directed toward intensified production and after the armistice to general readjustment.

However, the papers which were presented dealt with subjects of timely interest and constituted a valuable addition to the literature on overhead and underground transmission.

At the November meeting, held in Toronto, Mr. S. Svenningson presented a paper dealing with the construction of a 110,000-volt transmission line crossing the St. Lawrence River. The preliminary investigation, leading to the adoption of a single 4800-ft. span with 350-ft. towers, is outlined, together with a general description of the design and construction of the towers, insulators and cables. The provisions for protection from ice and method of calculating sag is also included.

At this Annual Convention a session is devoted to the presentation of papers covering both overhead and underground transmission problems.

Messrs. W. S. Clark and G. B. Shanklin, in a paper on high-tension single-conductor cables for polyphase systems, set 25,000 or 30,000 volts as the limit for three-conductor cables and point out the adaptability of single-conductor cables for voltages up to 55,000. The paper compares the dielectric, inductive and general line characteristics of single conductor and three conductor cables, discusses the advantages and disadvantages of each type and states that the induced sheath voltage or current is the only factor in single-conductor operation which requires serious consideration.

Mr. R. W. Atkinson presents a paper on the dielectric field in an electric power cable. The data given cover, particularly, the field of three-conductor, three-phase cables, and is primarily the solution by physical measurements, of some of the geometric problems of this type of cable. Methods are outlined by which it is possible to determine from electrical measurements certain specific quantities such as the permittivity and resistivity of the dielectric of three-conductor cables.

The potential stress distribution in three-conductor cables is given, most of the data being based on measurements with electrodes in an electrically conducting liquid, thus approximating closely a homogeneous dielectric. Some additional potential measurements were made with exploring electrodes built into a three-conductor cable having commercial insulating material.

Mr. A. E. Silver in a paper on the problems of 220-kv. power transmission suggests 220-kv. as the logical voltage for the high-capacity, long-distance transmission of energy from distant coal fields and water power plants. The author discusses very fully the important problems introduced by large concentration of energy at high voltage and covers in detail the economic and technical considerations underlying the design of a 220-kv. system. The paper indicates that while further investigation and research are necessary for a complete solution, established principles of design and present types of equipment can, with minor changes, be adopted for 220-kv. transmission.

The points brought out in the paper will aid in working out this advance in the field of high-voltage transmission by promoting constructive discussion and directing research along the lines indicated.

Mr. F. W. Peek, Jr. has given us the results of his investigation of the operating and protective characteristics of various types of spark gaps. The paper shows that there is a marked difference in the relative lightning spark-over voltages of different gaps, as well as a great difference in the settings imposed by operating conditions. Both of these factors must be considered in comparing relative protective values.

It is pointed out that the combination sphere-horn having electrodes of points, horns and spheres gives very good protection over the whole range of frequency or wave front. The spheres discharge the very steep waves and the horns the moderate waves, the points taking care of continuous high-frequency, static, and waves of very slanting front.

The comparative protective values of various types of gap are shown graphically and some fundamental points in the design of bushings and insulators are pointed out.

RECENT DEVELOPMENTS

High-Tension Insulators. There have been no radical changes in the design of high-tension insulators during the past year, and efforts along this line have been toward perfection of details and improvements in reliability.

A great deal has been written on the subjects of insulator troubles, but the difficulties experienced have been no greater than might have been expected in high-voltage work. It is believed that a proper appreciation of the factor of depreciation of insulators and the inspection and replacement of faulty material will go far toward improving operating results.

Practise has clearly demonstrated that a line which is liberally designed as regards insulators will operate satisfactorily in spite of a considerable amount of depreciation. As a result there is little doubt of the tendency to go to considerably higher voltages, wherever there is sufficient load to warrant a conductor large enough in diameter to keep down the corona losses.

The past year has seen the installation across the Tennessee River of the longest span in the world, the very heavy stress occasioned by this span being carried on a single insulator of comparatively small size.

Underground Cables. The material progress which has been made in the last few years in the field of underground cables may be traced to the growth in power requirements incident to the war, as well as to the more exacting demands of cable users.

The recent practical developments are a natural outcome of many investigations dating back to the papers of Gorman in 1901, Raynor in 1912 and Klein in 1913, all of whom clearly demonstrated the start of corona in paper insulated cables at stresses of between 25,000 and 30,000 volts. Developments in the United States have been closely paralleled in foreign countries.

Great general interest is shown regarding the subject of dielectric losses. This matter has become of great commercial importance in the last few years due to the increased loading of the conduit systems. A great variety of opinions exists regarding the actual importance of losses and particularly as to the temperatures at which these are most important. Standardization of ideas on these questions is desirable.

Several methods, with numerous variations, are being used for making dielectric loss measurements, the results checking very closely. However, on account of the magnitude and nature of the quantities sought, all of the methods require more care and skill than do the more usual measurements on electrical apparatus.

Many investigators have studied the problems connected with the stresses in dielectrics. Since there are inherent limitations to the development of the usual three-conductor cable, proposals have been made to avoid these. One plan involves the use of single-conductor cables and another the use of the electrical equivalent of three single-conductor cables but under one sheath.

One direction of present day development is toward the standardization by operating companies of larger sizes of transmission cables. One company is planning to install a large amount of 11,000-volt cable with conductors of 600,000 cir. mils, and 22,000-volt with 350,000 cir. mils. While this is not larger cable than has been made in individual instances, it is larger than has been standard practise for any company in the past. Another company is making a practise of operating two cables as large as 4/0, 26-kv. as a single unit.

There has been an increase in the use of split conductor cable for transmission line protection. Two large operating companies seem to have partly standardized on this type of cable for future installations.

Cable users are now fairly well informed as regards the operating temperatures of their cables. By comparatively simple means it is possible to obtain an accurate knowledge of conditions of an existing system. A large amount of data is in the possession of operating companies as regards temperature rises of conduit systems under different conditions of installation, and it would be of extreme value to the industry as a whole for such data to be made generally available. Existing systems which have poor cooling characteristics might be improved in some cases and the design of new systems would be greatly facilitated.

Operating companies understand much better than formerly the properties of cables which have to do with successful operation and there is an increasing tendency toward the elimination of non-essential features of specifications and for co-operation with manufacturers so that the latter will not be hampered in securing to the highest degree the essential properties some of which cannot yet be covered by specifications.

SUGGESTIONS FOR THE FUTURE

There has been considerable discussion during the past two years on the subject of dielectric losses in underground cables. Very little real progress appears to have been made, although several large cable users are planning to incorporate in their cable specifications a clause relating to dielectric losses.

Your Committee has been advised that cable manufacturers have been working on this problem with a view to standardizing equipment and methods of measurements, and it is recommended that succeeding committees give this matter their attention.

Allied very closely with the subject of dielectric losses, is the question of safe operating temperature of cables. Mr. R. C. Powell presented a paper which appeared in the PROCEEDINGS for August 1916, but very little additional information has been made available.

There is a growing tendency on the part of those operating high-tension transmission cables to base their current ratings on the heat dissipating characteristics of the individual duct line and there is no doubt that some progress has been made along these lines. It is very desirable that the Committee secure one or more papers covering this phase of underground transmission.

As regards insulators, it is very desirable that the results of tests conducted by Professor Ryan on the aging of insulators be made available, as this question is of vital interest in the operation and maintenance of high-voltage lines.

Referring again to the reduction in the membership of the Committee, your Chairman feels that the work would be greatly facilitated and the results of much greater value if the personnel were limited to not more than ten members.

E. B. MEYER, *Chairman.*

June 2, 1919.

ANNUAL REPORT OF THE INDUSTRIAL AND DOMESTIC POWER COMMITTEE

To the Board of Directors,

FOR two terms back, the Industrial and Domestic Power Committee has studied the general idea of investigating the application of electrical power to industry. During this term, the idea has been reduced to a definite plan, and the plan put definitely in motion.

It is impossible in this report to more than indicate the general features of the plan, its organization and personnel. Fourteen men, *i. e.*, the committee as appointed, started work in September, 1918. May 1919 finds the committee increased to 43, not including men who are helping in the work without committee recognition.

It was decided early in the term to actively prosecute the study of application of power in industries by the formation of sub-committees. Each sub-committee was to concentrate on its branch of the work, subdivide its activities as seemed wise and go right ahead. As it was questionable as to the correct final procedure, it was decided that the investigations would be based upon.

a. The application of electric power to specific processes,

b. The application of electric power to specific electrically driven machinery,

and that part of the sub-committees would work to one thought; the remainder to the other.

Nine sub-committees were formed, and have been under operation this term as follows:

1. Sub-committee on motors with particular reference to speed torque characteristics.

A. M. Dudley, Chairman.

R. H. Tillman	A. C. Lanier
Wilfred Sykes	John C. Parker

2. Sub-committee on Domestic Power Applications.

H. Weichsel, Chairman

James Dixon	C. L. Kennedy
A. F. Welch	A. M. Harrelson

Bernard Lester

3. Sub-committee on Applications in Printing Industry.
W. C. Kalb, Chairman
W. E. Date
J. C. Lincoln
John D. Nies
Carl F. Scott

4. Sub-committee on Applications to Cranes and Hoists.
W. L. Merrill, Chairman
H. W. Eastwood
E. Friedlaender
R. H. McLain

5. Sub-committee on Application to Machine Tools.
H. D. James, Chairman
T. E. Barnum
R. H. Goodwillie
W. T. Snyder
W. C. Yates

6. Sub-committee on Application to Passenger and Freight Elevators.
R. H. Goodwillie, Chairman
H. D. James
David L. Lindquist
H. P. Reed
Charles H. Roth

7. Sub-committee on Application in Textile Industry.
H. W. Cope, Chairman.
E. T. Foote
C. T. Guilford
S. B. Paine
D. H. Sadler

8. Sub-committee on Application in Cement Industry.
R. B. Williamson, Chairman
A. M. Dudley
H. Weichsel
C. A. Kelsey
Arthur Simon

9. Sub-committee on Application in Woodworking Industry.
L. E. Underwood, Chairman
Truman Hibbard
S. A. Staege

Under the plan, other committees will be formed and put under way as the work develops. Plans are also under way in the Office of the Secretary of the Institute to care for records from the sub-committee activities as they are turned in. The activities of the sub-committees are further interchanged through the Chairman of the Industrial and Domestic Power Committee, acting as an advisory personal clearinghouse.

The actual records of sub-committee work for the term are not numerous. Much time has been spent in planning the sub-committee work, determining its personnel and securing appointment thereof. Certain of the sub-committees have not advanced beyond this stage. All have submitted reports of activities for this term indicating full co-operative support from their associates and definite sustained interest in the work. In order to bring out more clearly the work in hand, excerpts from several of the reports follow.

From the sub-committee on the printing industry, Chairman Kalb reports the following divisions:

1. Press operation on raised surface or typographical printing, this to cover motor and control application for typical job presses, magazine and newspaper presses.

2. Contributory device operation relating to raised surface printing. This includes linotype, monotype, stereotype, electrotyping, conveyors or carriers, hoists, folders, paper cutters, tension devices and electric heating as applied to metal melting pots and bookbinding tools.

3. Types of presses used in surface and sub-surface printing, this to cover lithographic, planographic, rotogravure and embossing. This division will also include power application on bronzing machines and wood printing.

4. Contributory devices used in connection with surface and sub-surface printing and embossing.

Chairman Goodwillie indicates the work of the sub-committe on the elevator industry as follows:

Scope—The committee has undertaken the study of the electric elevator from the standpoint of its use, *i. e.*, fulfilling its purpose as a mechanism for raising and lowering vertically, passengers and freight in a hatchway.

The subject is being treated by considering comprehensively the requirements of elevator service and leading to the fulfillment of these requirements by the application of electric power to the motor and controlling devices.

The sub-committee on machine tool application has given much thought to its subject. Chairman James in part indicates his committee's plan as follows:

1. Control Equipment: This term will include the complete control apparatus, including disconnecting means and overload protection which is used for the control of the machine tool motor. The complete equipment may or may not form a single unit. Note: It has been common to speak of the machine tool controller as that part of the control equipment used for starting, stopping, reversing, or regulating the speed of the motor. In many cases, this controller did not include the disconnecting means and overload protection. It was, therefore, thought desirable to select a term which would include all of these items.

2. Application Requirements: It was agreed to divide the control equipment into two classes in reference to the features required for particular applications. These divisions are as follows:

    1. General Application Requirements: These requirements are common to all machine tool applications and it is recommended that they be incorporated in all machine tool control equipments. They are as follows:
        1. 1 Overload Protection.
        1. 2 Low Voltage Protection.
        1. 3 Enclosure or Equivalent Protection.
        1. 4 Disconnecting means.
    2. Additional Application Requirements.
        2. 1 Armature Speed Control.
        2. 2 Field adjustment for Speed Control.

2. 3 Reversing or Non-reversing.
2. 4 Manual or Automatic.
2. 5 Dynamic Brake.
2. 6 Drift.

The next item on the program will be to compile a list of machine tool applications which comprise only the machines more commonly used. This list will then be analyzed and the additional requirements needed for each application specified.

The sub-committee on the cement industry through its Chairman, Mr. Williamson presented the results of earlier activities in an admirable paper read to the Institute at its regular meeting November 8th, 1918. This meeting was held under the auspices of the Industrial and Domestic Power Committee. Chairman Williamson reports that his committee is collecting such additional data as will supplement this paper and in course of time it may be advisable to publish either a revision of it, or an appendix. As an example, we hope before long to secure some information regarding the application of synchronous motors in this industry. In course of time this additional information should add considerably to the value of the paper.

As a committee we feel that our work, and its plan is not only possible but practicable but that two perhaps three years are necessary to determine this. We feel that this plan should be continued another year and recommend this. We also call attention that it takes much time to get together a working personnel and so far as possible, and where not inconsistent with other plans, it is recommended that this existing personnel be kept intact, the recommendation extending to the sub-committees' makeup.

We must call attention to our belief that a certain amount of definite interest in the Institute is being generated by this plan of extending work among a large group. We believe Institute men are anxious to contribute service if a method be indicated. I believe that our sub-committee chairmen are helping materially in this, and their activities have resulted already in bringing several desirable electrical engineers on to our roster.

The committee particularly appreciates the prompt help and attentions which our executive offices in New York through the instrumentality of Mr. F. L. Hutchinson, have constantly rendered.

H. G. PIERCE, *Chairman*

ANNUAL REPORT OF THE LIGHTING AND ILLUMINATION COMMITTEE

To the Board of Directors,

I beg to submit on behalf of the Lighting and Illumination Committee the following report for the year 1918-19.

The activities of the Committee for the current year were composed largely of the plans for a session of the Institute for a discussion of Industrial Lighting Codes, this subject being one of those suggested by last year's Committee, but which, due to the abnormal conditions which prevailed at that time, could not be arranged. As the outcome of these plans a paper was presented by G. H. Stickney at a joint meeting of the Institute and of the Illuminating Engineering Society on April 11, 1919 in New York under the auspices of this Committee of the Institute. At this meeting Mr. Stickney presented an outline of the general scope and reasons for these codes. The session was highly successful and promoted valuable discussion on the part of representatives of the lamp companies, the state labor departments and manufacturers in general.

Another feature of the Committee's work during the present year has been the suggestion which the Chairman was authorized to make to all the Institute sections throughout the country calling attention to the advantage to be gained by devoting one of the Section meetings at each center during the current year to some aspect of Illumination, preferably as a joint session with the local branch of the Illuminating Engineernig Society where such a local branch existed. This suggestion met with a widespread response and a large number of the Institute sections devoted one meeting of the year to some particular division of the lighting and illumination fields and a number of valuable papers and discussions on this topic were presented before the local sections. In some cases the Committee co-operated with the local sections by suggestions as to possible speakers for illumination subjects.

At one of its later meetings, the Committee, following the suggestion of the Board's Committee on Technical Activities, decided upon steps to be taken in plans for presenting one comprehensive paper before the Institute during the coming year on "An Analysis of Daylight Saving," and a symposium on "Systems of Electrical Distribution for Street Lighting" at a later date.

According to the custom of the Committee during the past few years, and also acting upon the suggestion of the Committee on Technical Activities, the following brief summary of progress in electric illumination during the past year, is herewith presented.

PROGRESS IN ELECTRIC ILLUMINATION

Street Lighting. One of the effects of the war was to curtail street lighting installations throughout the country, existing systems being extended only when absolutely necessary, and work on new installations being practically at a standstill during the war. With the signing of the armistice, renewed activity has become evident in this field, and present prospects for extensive developments appear bright.

To illustrate the effect of the war on curtailment of installation work, the construction work on the extensive street lighting in Los Angeles and San Francisco were suspended during the war, but the work on these new systems was resumed almost immediately after the signing of the armistice. It may be added that the two installations here mentioned constitute, in themselves, notable achievements in the street lighting field. Other recent developments in street lighting include, among other cities, portions of Chicago, Denver and Dallas.

In the fixtures to be used with incandescent lamps in street lighting, there is an increased tendency to apply some form of prismatic refractor. New lanterns have been developed of both upright and ornamental bracket types, using dome shaped prismatic refractors with an outer globe, which has the effect of breaking up the concentrated rays without loss of the redirective value of the refractor. These units exhibit a bright, sparkling appearance which is considered desirable in street lighting if undue glare is avoided. They direct an unusually high proportion of the light to the street surface.

In recently designed street lighting systems there is an increased tendency to take advantage of the wide range in the incandescent lamps available for operation on circuits of the same kind, thus making it possible to select the lamp sizes according to the strictly engineering requirements of each given class of street and thus affording a far more effective illumination result for a given outlay than is possible with a single fixture and one given size of unit of either large or small size as the case may be.

Studies tending toward still greater flexibility in installation and extension of street lighting systems, and toward a reduction in the disproportionate investment charges which are necessary in the common form of series street lighting system, have led to the development of new plans and devices for current supply. A new automatic movable-coil constant-current regulator, in sizes up to ten kilowatts for pole mounting, and operation from a time clock or remote-control relay switch, is especially useful for the extension of street lighting at distances from substations.

Another promising development of street lighting is the operation of the street lamps from existing secondary multiple or house lighting circuits rather than from series circuits. This form of installation avoids the separate high-tension circuits, special transforming and regulating equipment and the cost of the high-voltage insulation for series systems. Small synchronous motor clock switches on the lighting circuits are available for controlling the lamps. Another proposed method is the use of simple remote control switches operated by a so-called pilot wire.

A great deal of interest has also been displayed in highway lighting, and there is a possibility that some of the states in placing contracts for road work will include the erection of suitable poles for the lighting of the state highways, on a larger scale than has been considered practical in the past.

The tendency for sharing the expense of ornamental street lighting between the city and property owners and merchants is illustrated by the action of the property owners and merchants to pay one half of the total annual cost for the ornamental street lighting in the Triangle District of San Francisco. A defense of proportionate sharing of this expense on a 50 per cent basis for the city and 50 per cent basis for the merchants and property owners, based on Syracuse, N. Y. conditions, has recently been discussed in one of the leading engineering weeklies.

Under war time street lighting economies, one interesting statement has been advanced that the average streets in this country require an increase of illumination of 70 per cent, but that a considerable reduction of white-way lighting could be afforded under extreme conditions like those during the war. The small percentage which the fuel used for street lighting bears to the total fuel used in this country has also been a matter of discussion, brought on by war conditions.[1]

Street lighting curtailment under war conditions, proved unpopular in a number of localities and cases have been cited where the popular demand for regular lighting conditions in the streets of a city or town was so great during the period of curtailment, that the regular lighting conditions were restored under pressure of public sentiment. In certain cases where curtailment of street lighting was carried out, interesting problems of rebates during the curtailment period were created.

Saving coal by efficient street lighting was an alternative to curtailment and one case which has been reported in a part of Chicago's street lighting system indicates an annual saving of about 3000 tons of coal by the substitution of type C Mazda lamps for arc lamps.[2] The magnitude of the street lighting in the larger cities may be realized from the published figures in New York City, where there are 2800 miles of lighted streets at an annual cost of about $700,000. to the city.[3]

To the foregoing, there might be added a list of the new street lighting units and standards which have been developing recently and which have made available a great variety of effective equipment for use in this field.

Protective Lighting. While the ideas of flood-lighting the fronts of buildings and yard surfaces with light from projectors, is not new, its use during the war has received increased attention as a vital measure of plant protection. This has resulted in an unusual appreciation of light as a factor of usefulness for industrial plants and undoubtedly has had some effect in convincing manufacturers of the necessity of higher intensities of interior illumination.

Factory Lighting. One of the most notable influences of the war upon the lighting field has been the widespread acceptance of the fundamental value of good lighting to factory production. The pioneer tests of Mr. Wm. A. Durgin, of the Commonwealth Edison Company in Chicago, on the relations of higher illumination intensities to factory production rates, has brought out forcibly the interesting fact that illumination is a factor of primary importance up to an intensity which makes vision possible, but even beyond this, an increase in the intensities to much higher values than those required for vision itself, bring about rather surprising results from what seems to be a stimulating effect of highly cheerful surroundings upon the employees, thus increasing production by percentages which are very large in comparison with the costs for the increased illumination.

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[1] J. R. Cravath in *American City*, October 1918, p 303.

[2] G. T. Dunklin in *American City*, June 1918, p 517.

[3] D. F. Atkins in *Modern City*, February 1918, p 13.

The importance of factory lighting in war work was also emphasized by the appointment of a National Committee on Lighting to act as a sub-committee of the Advisory Commission, Council for National Defense, referred to by last year's Committee in its report. The publication of a Code of Lighting by this Committee on Labor, with a suggestion that the Code be put in effect in every state in the country, has resulted in bringing these regulations before the various state authorities from a new standpoint. The paper by Mr. Stickney, found in another issue of the Institute PROCEEDINGS, contains an excellent summary of the developments in these codes.

Motion Picture Lamps. Considerable development work has been directed to the production of a satisfactory motion picture lamp. The use of the incandescent lamp for motion picture work will undoubtedly become quite general.

Searchlights for War Purposes. The searchlight has been of the utmost importance in the experiences of the recent war. The 60-inch searchlights first used by the Allies together with the automobile power plant and the truck, brought up the weight of each to eleven tons. Specifications which were prepared by American engineers during the progress of the war were directed to a reduction of weight to make the equipment more practical for army work, to the use of a 60-inch metal mirror, and to the greatest possible simplicity.

The so-called Lynn searchlight is now said to be the most powerful searchlight in the world, giving a beam of an intensity of over three times that of the most powerful searchlights in use at the beginning of the war. Moreover, the spectrum of the light from these units approaches a daylight character so nearly as to make them very useful in revealing aeroplanes at great distances above the earth's surface.

The importance of the searchlight is indicated by the general conclusion of army engineers that the only satisfactory method of meeting an aeroplane bombing operation is by means of searchlight defense. In fact it has been stated that the city of Bruges was never bombarded at night by allied planes due to the protection afforded by seventeen enormously powerful searchlights.

Automobile Headlighting. The two 1918 reports of the Committee on Automobile Headlighting Specifications of the Illuminating Engineering Society and the corresponding discussion as published in the TRANSACTIONS of that Society, March 20, 1919, constitute a valuable fund of information on this subject. The Committee on Lighting Legislation of the Illuminating Engineering Society has recently formulated proposed regulations for incorporation in a model law in regard to headlamps on motor vehicles. The Specifications for Headlight Tests of New York State are also of interest in this connection.

C. E. CLEWELL, *Chairman*

ANNUAL REPORT OF COMMITTEE ON ECONOMICS OF ELECTRIC SERVICE

To the Board of Directors,

DURING the first half of this Institute year your chairman and three other members of the Committee were in military service. It will be readily appreciated by anyone who was in active service in engineering and construction lines that there was consequently no opportunity to carry forward the work of the Committee. This should not be considered as an index of the importance of a Committee on Economics of Electric Service to the Institute. During the past year the normal conditions in connection with electric service were so disarranged that there was little such a Committee might have done except record the effects of war conditions on the service, which might have become of historic value but which could not have had any considerable immediate usefulness. Last year the Committee took charge of a New York meeting of the Institute, presenting a paper on The Effects of War Conditions on the Cost and Quality of Electric Service which served its end in bringing people to a lively appreciation of the almost incredible effects the war conditions had on electric service and the great difficulties the managers of electric properties were forced to face in continuing effective service at reasonable prices during the war. The preceding year the Committee took charge of a meeting considering, in five papers, the matter of valuations of properties, and the production of effective inventories both for use in valuations in the regular operations of the properties.

Now that the war is over electric service will gradually become normal, both in the matters of cost and character, but it is not to be expected that conditions will return to those of pre-war times. It is therefore important that the Committee on Economics of Electric Service should keep careful account of the matters under its jurisdiction and by timely reports and papers enable the Institute to assist in bringing out from the rather chaotic war conditions sound and reasonable bases for the establishment of electric service under the new conditions. It is important also that this Committee of the Institute should work in cooperation with committees of like scope of other organizations, including those of a more or less commercial character, so that these economic questions both as to cost of service, quality of service and value of properties may be solved for the future from as broad a point of view as possible. The Institute's place in this work should be an important one as the recognized leader amongst purely technical societies having particular regard for electrical matters.

WM. B. JACKSON, *Chairman.*

ANNUAL REPORT OF THE PROTECTIVE DEVICES COMMITTEE

To the Board of Directors.

SHORTLY after the signing of the armistice last November, there were indications that the members were rapidly discontinuing their various war activities, and upon making an attempt to resume the work of the committee, which had been practically dormant during the war, it was found that the members of the committee and the members of the Institute with whom they were in correspondence, were in general, ready, willing and anxious to co-operate in the work of the committee. Work on the Relay Questionnaire was, therefore, pushed rather aggressively and was discussed in several meetings of a subcommittee and later in meetings of the Protective Devices Committee. The result of this questionnaire and of the committee work appears in the form of papers which are to occupy one of the technical sessions of the Annual Convention.

The future activities of the committee were discussed at some length at one of its meetings. The questionnaire had, in the opinion of the members of the committee, brought forth information so interesting and valuable that it was their opinion that similar investigations should be undertaken by the committee and that for this purpose the number of members on the committee should be increased so as to permit the investigation of more than one subject at a time. The subjects for investigation recommended by the committee, in the order of preference, are as follows:

1. Schemes of Relay Protection.
2. Oil Circuit Breakers.
3. Grounding of the Neutral.
4. Lightning Arresters.
5. Current Transformers.
6. Potential Transformers.

In connection with the work on the Relay Questionnaire it was brought out by several members of the committee and by several of the members of the Institute with whom we corresponded during the work of the questionnaire, that in a number of cases the operating companies were experimenting with various types of relays and schemes of relay protection, and that there were no facilities for co-operation or for comparing experiences so that each of the parties interested in such matters could get the benefit of the experience of all. In some cases it was found out that one company was at some expense investigating a particular type of relay for a particular purpose, and that another company a year or two earlier had made the same experiment under practically identical conditions and had found that the relay was not adapted for the purpose. It is, therefore, recommended that the Protective Devices Committee undertake to devise some scheme of facilitating co-operative research on subjects within the scope of the committee and that the scheme include some method of communicating, at regular intervals, to the engineers who are co-operating in this manner, such information as has been developed by all of the contributing members.

D. W. Roper, *Chairman.*

ANNUAL REPORT OF ELECTROCHEMISTRY AND ELECTROMETALLURGY COMMITTEE

To the Board of Directors,

TECHNICAL papers on electrochemistry and electrometallurgy, involving chiefly chemistry, physical-chemistry and metallurgy, are naturally discussed more intelligently, more critically and more effectively, in our sister society, The American Electrochemical Society, which includes in its membership most of the chemists, physical-chemists and metallurgists who are interested in such subjects. Hence papers on these subjects naturally drift to and belong to that society.

In connection with many electrochemical and electrometallurgical plants there are however features of a purely electrical character which chemists, physical-chemists and metallurgists are not able to discuss critically and intelligently, such as regulation, power factor, load factor, balancing of loads, different kinds of currents, long-distance transmission, relative advantages and costs of water power *vs.* steam power, etc. Papers on the latter subjects ought to go to the A. I. E. E., or perhaps better yet, be presented at joint meetings of these two societies. Although the Chairman of the present committee has endeavored to procure papers of this kind, he has not yet been successful.

The Chairman recommends that the above plan be adhered to, and that there should be no rivalry but rather a mutually beneficial cooperation between these two national societies. As joint meetings are difficult to arrange, it might be advisable that in case of a particularly good paper on an overlapping subject, arrangements be made that such a paper might become the joint property of both societies, be read and discussed at the meetings of both societies, and be published in both TRANSACTIONS.

CARL HERING, *Chairman.*

ANNUAL REPORT OF THE ELECTROPHYSICS COMMITTEE

To the Board of Directors,

IT has been the endeavor of this committee for the last few years:

1. To encourage original papers of high technical standard, marking advances in electrophysics.

2. To have each year a broad, interesting, general lecture, free from mathematics, dealing with modern physics.

3. To promote a more complete cooperation and mutual understanding between the engineer and the physicist.

This general policy has been endorsed by the present committee.

The following are the activities of the committee for the past year:

LECTURES

"Lectures on Research". Drs. Whitney and Millikan. October 1918. Philadelphia. Arranged by the Committee of 1917–1918.

"An Evening with the New Astronomy". Dr. John A. Brashear. Mid-winter Convention, 1919. New York. Arranged by Meetings and Papers Committee.

TECHNICAL PAPERS

A technical session devoted to electrophysics was held at the Mid-winter Convention. The following papers were read:

"Ionization of Occluded Gases in High Tension Insulation", G. B. Shanklin and J. J. Matson.

"The Dielectric Strength of Air Films Extrapped in Solid Insulations". F. Dubsky.

"Abnormal Voltages in Transformers". L. F. Blume and A. Boyajian.

It is difficult for the engineer to keep up with the rapid evolution and progress in modern physics, as most of the work is clothed in mathematics and appears in philosophical magazines never read by engineers. The general lectures were arranged to overcome this, and have proved very successful and popular.

It is hoped that arrangements for a joint meeting with the American Physical Society can be made soon.

F. W. PEEK, JR., *Chairman*

ANNUAL REPORT OF THE TELEGRAPHY AND TELEPHONY COMMITTEE

To the Board of Directors,

A NOTEWORTHY development during the past year has been the drawing together of the arts of telegraphy, telephony and radio signaling into one subject of Electric Communication. War conditions have very materially aided this tendency. The enormous increase in traffic, due to the war, made it imperative that each method of rapid, long distance communication be developed to its utmost capacity.

With the entry of our country into the war, the requirements of the military and naval authorities imposed a certain amount of concentration in the direction of communication facilities, and, when on July 31, the Postmaster General was empowered to take control of all telegraph and telephone lines in this country, unity of direction was further advanced.

On December 1, the facilities of the two large commercial telegraph companies were consolidated, and on December 4, the marine cable systems of the various cable companies were taken over by the government.

From an engineering standpoint these developments had a retarding effect upon the plans of the private companies for apparatus and construction improvements; but several Boards appointed by the government were given opportunity to experiment with suggested technical improvements, and to distribute traffic loads where they might be moved in the most expeditious manner possible over the lines of the combined systems.

STANDARDIZATION

During the year a considerable amount of contributory work has been done along the line of standardizing telephone, telegraph and radio terms, and symbols.

RAILROAD COMMUNICATION

The Association of Railway Telegraph Superintendents was, during the year, absorbed by the American Railroad Association; but the engineering work carried on by the Association has not been neglected by the railroad telegraph and telephone officials. Indeed, the manager of the Telegraph Section of the Railroad Administration has been enabled to coordinate technical effort to the end that the railroads will undoubtedly benefit from the work done by technical committees.

LIGHTNING PROTECTION

During the year considerable improvement has been made in the design of lightning protective apparatus used to safeguard telegraph and telephone lines from lightning and accidental contact with foreign wires carrying higher potentials than the signaling circuits. The vacuum type of arrester has been improved in effectiveness and reliability.

PRINTING TELEGRAPHS

On the lines of the Western Union Telegraph Company the use of the multiplex printer system has been considerably extended. About 80 per cent of this company's wire traffic is now handled by means of the Multiplex, and the Morkrum printer duplex systems. The Postal Telegraph-Cable Company, on the other hand, which has experimented during the past twelve years with three different printing telegraph systems, on April 1, 1919 discontinued the use of printing telegraphs on all of its lines, reverting exclusively to the Morse manual system.

SUBMARINE CABLE SIGNALING

During the past year considerable improvement has been made in the traffic carrying capacity of submarine telegraph cables. The application of the cable relays and amplifiers invented by Heurtley, Dixon, Brown, Gulstad, and Bruce, to cable operation, has made longer direct-working possible, and has resulted in increased speeds in words per cable n unit time. On the cables operated by the Western Union Telegraph Company between Hearts Content, Newfoundland, and Valentia, Ireland, the printing telegraph system has been applied with satisfactory results.

[The following contributions to this report are submitted by the members of the Committee whose names appear under the various subheads.]

TELEGRAPH LINE CONSTRUCTION

R. E. CHETWOOD

No radical changes in the design or type of telegraph construction have been made during the past year. There has, however, been a decided tendency towards stronger construction, both for the pole line and for the wires. Stronger pole line construction has been obtained by using more poles per mile of line, by using stronger poles and by the use of as short poles as right-of-way conditions will permit.

Developments in the telegraph art which lessen the harmful effect on telegraph transmission of the high electrostatic capacity of conductors in cables have permitted the use of aerial and underground cables to a somewhat larger extent than formerly. Stronger and more reliable construction has thus been obtained in and near cities where, on account of right-of-way conditions, it is often necessary to carry the wires of two or more pole lines on one line.

As iron wire is a satisfactory conductor for many classes of telegraph circuits, both with manual or with automatic operation, a considerable increased strength in line wires has been obtained by using iron wires of large size, such as No. 4 and No. 6 B. w. g.

INTERFERENCE TO COMMUNICATION CIRCUITS FROM NEIGHBORING POWER LINES

A. W. COPLEY

A mutual interchange of information and co-operative work between power companies and communication companies toward the solution of inductive interference problems in particular cases, has resulted in improved conditions, and at the same time, caused the maintenance of friendly relations between the parties.

Conditions obtaining on the power circuits during regular operation are given the greatest attention working out the solution, as serious interference under such conditions is intolerable. Abnormal transient conditions, such as short circuits on the power lines, are of comparatively infrequent occurrence and short duration, and if protection of the communication circuits against interference at such times were to be generally attempted, the cost and inconvenience of the arrangements would be out of all proportion to the benefits gained. It is, therefore, considered reasonable to protect only against physical damage to the property or personnel of the communication company under such abnormal conditions.

For the prevention of interference in telephone circuits under operating conditions, co-ordinated transpositions of the power and telephone circuits give a solution in most cases. Wave-form correction in the power circuits by resonant shunts or other means, may sometime be resorted to, especially when transpositions are impracticable. There has been no standard in the past by which the tendency of a machine to cause telephone interference could be measured. The new telephone interference factor now defined in the Standardization Rules provides a measure of this tendency and its use will assist in the adjustment of interference difficulties.

Telegraph interference from transposed power circuits is so small as to be negligible, except during abnormal conditions. In cases of interference from power lines which cannot be transposed, such as trolley circuits, the use of resonant shunts in the telegraph circuits has given very good corrective results. Much has been accomplished in the prevention of interference from such circuits by a careful layout of the power system, particular regard to substation locations being given, so as to minimize the inductive interference in the communication lines.

LONG DISTANCE TELEPHONE TRANSMISSION

O. B. BLACKWELL

The features of perhaps greatest general interest at this time in long distance telephone transmission are telephone repeaters, loading, and multiplex-telephony.

The vacuum tube amplifier has been highly developed for use in telephone repeaters and has become the preferred form of amplifier for such use. The transmission gains which may be obtained with such an amplifier in two-way operation depend in each case on the electrical conditions of the line in which used. This has had a large effect on cable and line construction.

In the loading art it has required the development of coils having especially great magnetic stability and uniformity. Such electrical stability is also particularly important on long circuits which are composited for Morse operation to prevent the telegraph interfering with the telephone transmission.

The repeater and loading developments have considerably extended the use of telephone cables for long distance transmission. They have, however, made it imperative to keep open wire circuits as free as possible from cable in order to prevent such electrical irregularity from reacting on repeater operation.

A multiplex telephone circuit has been put into commercial use between Baltimore and Pittsburgh, giving four circuits over a single pair of wires in addition to the ordinary telephone circuit over the same pair. This multiplexing depends on the use of "carrier currents." In order, however, to be effectively transmitted over telephone circuits, these carrier currents are of comparatively low frequency and the ratio between them and the telephone frequencies being transmitted is, therefore, low. This brings in peculiar problems in the handling and separating of these different frequencies on the one pair of wires.

The vacuum tube plays an important part in this system, not only as an amplifier but also as a modulator and demodulator. The transmission of these frequencies over telephone circuits makes more severe requirements on the circuits than do ordinary telephone frequencies in view of their larger attenuations, the greater effect on them of lengths of cable and their increased tendency to crosstalk. The multiplex system promises to have a considerable field in comparatively long distance telephone service.

TELEPHONE OUTSIDE PLANT PRACTISES

W. R. McGOVERN

At the present time the best practise in outside plant construction is represented by an all cable and twisted pair distribution in the medium and large exchange districts. In the small exchanges where estimates of future growth do not show the need along any given route for more than from 10 to 15 circuits, it is more economical to use crossarm construction with galvanized wire. Even in these exchanges it is desirable to place a small amount of cable in the immediate vicinity of the exchanges.

In those exchanges where cable and twisted pair wire are used, the cable portion of the plant should be so designed, and supplied with distributing terminals, that the amount of twisted pair wire is held at a minimum. In thickly populated areas the twisted pair wire should appear only as the connecting link between the pole route and the subscribers premises.

The dividing line between the underground and the aerial portion of the cable plant is a variable determined by local conditions, but in general the circuits should be placed underground, if estimates of growth for several years in the future show that they will exceed a few hundred in number.

Among the tendencies of telephone construction is the more extended use of fine-wire cable, it being theoretically practicable to use 24-gage, or smaller circuits in the zones near the exchanges. The use of small-gage wire in the aerial cable plant will result in economy; and a more extended use of fine-wire cable in the underground plant will conserve conduit space as well.

Another tendency is towards the use of cable terminals of such a type that potheads are unnecessary. The so-called sealing chamber type of terminal allows paper cable to be taken directly into the terminal, and its use will become more extended in the future.

STATUS OF AUTOMATIC TELEPHONY

ARTHUR BESSEY SMITH

There is at the present time a general recognition that automatic telephony has arrived. It has been established that automatic switching is very flexible, offering a number of solutions for every traffic problem.

The switching apparatus has become fairly well standardized as to mechanism, electrical circuits, processes of manufacture and maintenance. The recent trend of development has been along the line of increasing the factor of safety, making more definite the standards of adjustment, and increasing the life of parts subject to wear.

Automatic switching is a recognized efficiency device for many classes of service. The private automatic exchange is widely used in commercial institutions, either isolated or with trunks to the public system. It is maintained by ordinary electrical employees.

The rural automatic telephone has become firmly established. It is served by party lines from a city central office or from a small switchboard at the center of the rural area. Common battery is successfully used for voice transmission as well as for dialling.

Single office and multi-office exchanges up to 70,000 lines are in use and have proved their adequacy. The application of automatic switching to metropolitan areas is a recognized possibility.

The automatic switching of toll lines is established. It is possible to dial directly from the originating toll board to the called party's telephone. This has increased the time-efficiency of toll lines.

ARMY SIGNALING

E. B. CRAFT

The telephone has become an essential part of the modern war mechanism. Because of the vast territory and enormous masses of men involved in military operations of the past four years, the military telegraph has assumed an entirely new character.

We now find networks of wires and cables reaching from all points of the fighting zone back to bases of supply often hundreds of miles away. These networks make use of the most modern developments of the communication art, such as high speed printing telegraphs and telephone repeaters for long distance circuits.

While necessarily of a temporary type of construction, these wires systems with their exchange centers, compare in magnitude and complexity with those of our large industrial centers.

Probably the most important development and one which will have the most far reaching effect upon the art in the future, relates to the development and application of thermo-ionic devices. The design and manufacture of these devices commonly known as vacuum tubes, has been placed upon a basis which probably could not have been reached within a decade under normal peace time conditions.

Some of the more important applications comprise the following:

Radio telephone for communication to and between airplanes while in flight.

Determination of direction by radio compass.

Signaling through the ground by means of leakage currents.

Overhearing of enemy operations through the use of energy amplifying devices.

As a result of the intensive development of the past two years there has been made available to the engineer, a device which will in the future undoubtedly play an important role not only in the communication but in other branches of the engineering world.

RADIO SIGNALING

JOHN STONE STONE

Radio engineering has continued to feel the powerful stimulus of the World War.

Secrecy has necessarily veiled a considerable amount of the original discoveries and inventions made in this field as well as the complete statistics which would disclose the enormous expansion of the manufacturing industry in this line during the past year, because all the development and manufacture were necessarily conducted for the military and naval services and under strict governmental observation and regulation.

The general tendency has been towards a more systematic and sound engineering development of radio communications. Sustained-wave-train radio telegraphy has, to a great extent, replaced the older and less satisfactory damped-wave-train, or spark system, while radio telephony has been developed into a most practical form for air plane service as well as for land and ship stations.

These advances have largely been the fruit of careful quantitative studies of the audion, resulting in the possibility of accurately predetermining its design when it is to be used either as an oscillating generator, detector, amplifier or modulator.

Advances have been made in minimizing "interference" and the amount of radiated power which can be effectively "modulated" by the voice has been increased with a considerable resulting increase in the range of radio telephony.

DONALD MCNICOL, *Chairman*

ANNUAL REPORT OF THE MARINE COMMITTEE

To the Board of Directors,

THE status of the application of electricity to merchant vessels was such that at the beginning of this season's Institute work it was deemed necessary to greatly enlarge the membership of this Committee. In previous years the shipbuilding industry comprised about five or six fairly large size steel shipbuilding plants. The representatives of these companies as well as the representatives of the few manufacturing concerns which supplied the shipyards comprised the Marine Committee. These gentlemen were fully informed as regards the methods of installation and the various requirements of the classification societies, ship owners, naval architects, etc., so that standard requirements in the nature of governing rules were hardly necessary. The war brought about a great expansion in the shipbuilding industry with the outcome that a great many men were brought into the newly organized plants to perform the work of electrical applications. It seemed fitting to bring these new men into contact with the more experienced members of the Institute and to prepare for all concerned some guiding regulations to make for the proper development of electrical installations on board merchant vessels.

Seven meetings of the committee were held. The first few meetings were used for the purpose of organizing both the committee itself and the work to be done. To this end subcommittees on the two main questions pertaining to the work were appointed. These main committees were called the Ship Installation Committee and the Electric Ship Propulsion Committee. The Ship Installation Committee was further subdivided into a Power Apparatus Committee, a Lighting Committee, and a Distribution Committee.

The sub-committees of the Ship Installation Committee prepared the necessary details pertaining to the recommendations and reported in conference to the Ship Installation Committee. In turn the Ship Installation Committee laid the results of its work before the Marine Committee proper. I, therefore, have the pleasure of submitting for the consideration of the Board of Directors the report of the Merchant Ship Installation Committee which establishes the Rules and Requirements as approved by the Marine Committee.

This report speaks for itself as regards the activity of the Ship Installation Committee. It may be stated that the work of the Ship Propulsion Committee has shown a similar amount of work but the nature of its investigations preclude the incorporation of the data that have been made, as the status of this application does not admit of the definite formulation of Rules and Requirements. I am attaching, however, as an addenda to this report a considerable amount of exceedingly interesting and important material which cannot at this time be put into print but will remain in the files of the Institute for the work of the Committee next year.

The undertaking of this work as is always to be expected grew with the investigations made by the sub-committees so that the work of the Ship Installation Committee is by no means complete. There are five items which though acted upon by the Power Apparatus Committee and the Lighting Committee were not considered by the main committee. There are seven items still to be completely considered by the sub-committees. In general, these subjects include such questions as the following:

(completed by sub-committee)

Control Equipments.
Alternating current apparatus control.
Radio installations.
Running lights, etc.
Fire-alarm systems.

(not completed by sub-committee)

Tabulation of generating sets.
Storage battery installation.
Gyro-compass installation.
Gyro-stabilizing installation.
Tabulation of wires and conductors.
Appliances in vicinity of compass.
Inspection report to Classification Societies.

The data pertaining to these questions are not to be printed but are attached as an addendum to this report for the benefit of the committee next year.

The attendance at the meetings of this committee have all been large and representative. The committee membership as a whole is to be congratulated upon the work accomplished. The Chairmen of the main committees as well as the sub-committees have worked earnestly and faithfully. It is to be expected that next year, by following the work here begun, that the Institute will be enabled to lay down the first requirements for marine installations that have ever been made. It is suggested that next year the concluding work of the committee should be done in conference with the Classification Societies and the Bureau of Standards.

H. A. HORNOR, *Chairman*

ANNUAL REPORT OF COMMITTEE ON USE OF ELECTRICITY IN MINES

To the Board of Directors,

I BEG to submit the following report regarding the activities of the Committee on the Use of Electricity in Mines for the past year.

The Committee provided papers for one session of the Philadelphia Meeting at which time a paper on "The Use of Electric Power in the Mining of Anthracite Coal", by J. B. Crane, Vice President, Lehigh Navigation Company, and a paper Drum Shapes as Affecting the Mine Hoist Duty Cycle and Motor Rating," by F. L. Stone were presented.

Having been Chairman of the Schenectady Section during the past year has prevented me from devoting as much time to the Committee Work as I would liked to have given to it. However, I have given considerable thought to the question of making the activities of this Committee felt among mining men, and while I have no definite plans to recommend for doing so, I do believe that closer cooperation between the various technical societies, both national and local branches, will prove very beneficial. As the Committee on Development has this whole matter in hand at the present time I have taken no action with reference to it other than a talk with our local representative on this Committee concerning the question.

K. A. PAULY, *Chairman.*

ANNUAL REPORT OF THE IRON AND STEEL INDUSTRY COMMITTEE

To the Board of Directors,

THE increase in the use of electrical energy in the Iron and Steel Industry in the last few years has been remarkable and partly responsible for the prominent position the United States has taken in furnishing steel products to the entire world.

Over 500 motor equipments are in use in this country, driving main rolls with a maximum horse power of over 850,000, while the total horse power of auxiliary motors exceeds 1,350,000, making a total of 2,200,000 h. p., which requires about 650,000 kw. in generator capacity. In addition, electric furnaces require approximately 250,000 kw. in generator capacity, or a grand total of 900,000 kw. generator capacity in the iron and steel industry.

This is by far the largest amount of electric energy required in any one industry, and from all indications will continue to increase considerably in the future.

The activity of the Iron and Steel Industry Committee has mainly been confined to arranging joint meetings with the Association of Iron and Steel Electrical Engineers for the purpose of presenting and discussing technical papers of interest to members of both societies.

Practically all members of the A. I. E. E. especially interested in the steel industry are members of the A. I. & S. E. E., and attend the latter's technical monthly meetings and yearly conventions.

While members of the A. I. E. E. are primarily interested in the design and development of electrical apparatus, the membership of the A. I. & S. E. E. consists mainly of men having responsible charge of electrical machinery in the steel industry and is primarily interested in the installation and operation of electrical apparatus.

It is suggested that both societies closely co-operate, keeping in touch with the latest and best practise and progress in the art, and avoid duplication of effort as much as possible.

One of the main subjects to be taken up jointly by the two societies is "Standardization." In general, the Standardization Rules of the A. I. E. E. have been adopted by the A. I. & S. E. E. however they cover primarily standardization of terms and conditions which characterize the rating and behavior of electrical apparatus without going into details of construction.

The Standardization Committee of the A. I. & S. E. E. feels that for its work, standardization rules should also refer to such details and dimensions as will reduce cost and complexity and not retard progress in design and development. In its *Proceedings* of 1917, Mr. H. D. James, then Chairman of "Co-operative Standardization," expresses himself very ably in regard to advantages of Standardization as follows:

> Those interested in the application and manufacture of electrical apparatus realize the many advantages in standardizing equipment. Not all, however, stop to analyze these advantages, and in order to bring these to your attention, the Standards Committee wish to present the following advantages of standardization:
>
> 1. The best average equipment is obtained when a considerable number of qualified persons is willing to agree upon a particular arrangement. Such an agreement is based upon the available facts and when the personal bias of individuals is eliminated.
>
> 2. The adoption of a standard by an association tends to establish engineering and commercial practise in that particular field. The first approximation towards standards crystallizes criticism and suggestion, so that the tentative standard may be improved.
>
> 3. A standard equipment enables operating men to interchange parts of an equipment between different machines and reduces the number of spare parts required.
>
> 4. A standard equipment enables the manufacturer to carry this equipment in stock, so that prompt delivery can be made. It also reduces the misunderstandings which sometimes arise regarding the details of such an equipment.
>
> 5. A standard equipment permits the manufacturer to organize his work so that a better product can be obtained at a reduced cost.
>
> 6. A standard equipment saves the time of an executive. It enables him to delegate his authority to a subordinate where the choice of the equipment is limited to recognized standards.
>
> 7. Standard equipment simplifies the work, of the purchasing departments. Where standards have been agreed upon, price forms can be issued and a great deal of delay incidental to the purchase of this apparatus will be avoided.
>
> 8. In making plans for the application of electrical equipment to the various types of machinery required, the draftsmen will have available standard outline drawings, together with weights and dimensions, so that he may proceed expeditiously with his work.
>
> 9. Where equipment is agreed upon, the question of the mechanical interchangeability of parts can be more readily considered; for instance, the mechanical dimensions of a grid resistor frame.

10. Standard equipment will concentrate the attention, and increase the number of research investigations to improve this standard equipment.

11. The adoption of standards indicates the stability of any art, showing that it has passed through its initial stages and has become a recognized factor in the industry. This results in placing engineering upon a higher plane and commands the respect for those engaged in this particular art.

12. It is important that the electrical engineers of the Iron and Steel Industry take an active part in national standardization, so that the requirements of their industry may receive proper consideration in parallel with the standardization work of other organizations.

Standardization forms the basis of a great deal of our work. We are accustomed to take for granted many of our standards, such as weights and measures, screw-threads, pipe fittings, standard time, standard railroad gage, etc. Every direction we turn we see evidences of standardization. If it were not for these every-day standards, it would be very difficult for us to do business or to design apparatus. Standardization of motors, controllers, cranes, etc., is the carrying out of this general idea, which has existed for generations among civilized people.

Manufacturers of electrical apparatus should get together for real co-operation, to a much greater extent than they have done in the past, and not stop in the standardization of characteristics, voltages, frequencies, ratings, torque, etc., but begin to standardize mechanical dimensions, shafts, gears, pulleys, etc. They are generally in sympathy with the subject of standardization, but think it is the duty of the user of electrical apparatus to first decide on the proper standards and then co-operate with them, so as not to interfere with the progress of the art.

The problem then before us is to find the proper standards; the first step towards solving this problem should be to make general requirements for the installation and operation of electrical apparatus in the steel industry as uniform as possible.

It is suggested that the Iron and Steel Industry Committee take up this work jointly with the A. I. & S. E.E., and formulate a plan by which sufficient practical and theoretical data can be collected through the members of both societies, and finally draft standard rules for the installation and operation of electrical apparatus in the iron and steel industry. A great amount of detail work and time will be required to carry out this plan, and the closest co-operation of all members of both societies interested in this subject will be required.

It is recommended that the "Board of Directors" of the A. I. E. E. confer with the Executive Committee of the A. I. & S E. E. in regard to this subject.

E. FRIEDLAENDER, *Chairman.*

ANNUAL REPORT OF THE INSTRUMENTS AND MEASUREMENTS COMMITTEE

To the Board of Directors,

THE Committee during the past year has had the difficulties and handicaps incidental to the war period to contend with, but these were borne by all similar committees and associations so that nothing is gained by amplifying them in this report.

Several meetings were held and in addition an effort was made to transact as large a volume of the business of the Committee as possible by correspondence. The Committee has been responsible for the preparation of several papers on subjects relating to the functions of the Committee and while some of these papers have been completed, others are still in preparation. It has not been possible, however, to present any of these papers due to the crowded calendar of meetings. It is strongly recommended, however, that a session be set aside, possibly at the next Mid-winter Convention, for a group of papers on the subjects within the scope of this Committee. Justification for such a session is based on the success of the similar session held during the initial year of this Committee's activity.

The Committee through its membership was active with the Bureau of Standards working with the War Department to standardize purchase specifications for electrical instruments and accessories for overseas service, and joined in other governmental activities within the functions of the Committee.

The demands of the Government for standard instruments, for special designs of the standard types and for instruments to meet requirements new to the art, required a development of far reaching magnitude. The Institute was largely represented in the personnel engaged in this work and early in 1918 the output met the needs of the Government in all its special fields and met as well the unusual demands of the country.

The appeal by the Government to manufacturers heretofore specializing on a particular line of instrument or accessory to undertake the manufacture of instruments or accessories foreign to their regular production, resulted not only in increased production but the enlisting of resources and individuals new to a given problem. Not only did this produce the increased quantity desired by the Government but also resulted in a greatly improved product from a technical standpoint.

Space does not permit other than a passing reference to these developments, some of which are briefly summarized herewith:

HIGH SENSITIVITY MEASURING DEVICES

Prior to the war thermoelectric couples had been employed for measuring low values of alternating current. These couples were almost exclusively of German manufacture and not extremely accurate nor sensitive. There have since been developed and put on the market, thermoelectric couples of American manufacture which are superior in every way and are now available for the accurate measurement of alternating currents of any frequency. Their sensitivity is such that a current of one milliampere will produce a deflection of 3 millivolts in a direct current voltmeter.

The recent perfection of the thermoionic tube has put into the hands of the physicist and engineer, a new device for use in measurements of precision. By means of thermoelectric amplifiers, very feeble currents may be greatly amplified and their properties studied.

A peak voltmeter has been developed which makes use of the unilateral properties of the thermo-ionic tube. With this device it is possible to measure the instantaneous potential between any two points in an electrical circuit, without conuming any part of the power in the circuit and without disturbing its electrical constants.

Vacuum gages of high precision have been developed, making use of these tubes. Pressures from 0.001 millimeter down can be directly measured.

Quantity production of hot wire ammeters.

Bureau of standards Type D decremeters.

Wavemeters.

Consideration of the foregoing and the uses to which they were put in Government service, will make it apparent that some of the very significant developments, while valuable material for the Institute, could not properly during the major portion of the year, be made the subject of papers or reports.

The widespread use of maximum demand apparatus requiring accurate timing and synchronous operation renders very interesting the development of the Warren timing element and system.

The Warren self-starting synchronous motor constitutes a very accurate time-keeping element in the space of 2⅛ by 2⅝ by 2 9/16 inches capable of delivering more power than many of the present spring driven clocks, and this without the usual weekly or monthly winding. It is, therefore, particularly adapted for use in graphic and demand meters, time switches, etc. where the advantages of a time-keeping element with such characteristics are obvious. An even more important asset, for certain applications, than any of those mentioned, is that it is possible to synchronize the records of graphic or demand meters—a feature which heretofore has been very difficult to accomplish.

The small timing element can be installed in any device connected to the alternating current mains of a company where constant speed and synchronous operation are desired. The element itself, when combined with an accurate clock, is used as a master clock at the central station both for providing uniform time throughout the system and for regulating frequency.

S. G. RHODES, *Chairman*

ANNUAL REPORT OF EDUCATIONAL COMMITTEE

To the Board of Directors,

FROM September 1918 to January 1919, all the principal colleges in the country were under a military rule in connection with the Student's Army Training Corps. During that time the activities of the institution of learning and their policies were governed entirely by the War Department and its Educational Committee. Before the armistice it looked as if such an arrangement would continue throughout the whole academic year, and for this reason, your committee did not make any effort to plan its work, merely keeping itself in readiness for an emergency.

After the disbandment of the Student's Army Training Corps the colleges found themselves facing many difficult problems on account of extremely confused scholastic records of many students, mixed schedules, lack of instructors, and the necessity of finishing the academic year in such a way that a large number of students, including those discharged from the regular army, could start the next academic year with a clean slate. The committee did not feel, therefore, that the time was opportune for discussing any general educational policies, or sending out questionnaires, until conditions became more normal.

At one time during the war there was considerable talk about radical changes in technical education, as part of the general plan of reconstruction after the war. It seems, however, that the colleges of engineering are essentially going back to the pre-war standards, methods, and curricula. An investigation recently made by one of the leading technical journals, among the principal schools of engineering in the country, has shown an overwhelming majority of the deans and professors to be in favor of no radical changes from the ante-bellum methods.

Educational reconstruction, if any, will have to follow and not precede the general economic and industrial reconstruction. The country as a whole first has to decide what is technically and economically right, what is feasible to accomplish and what kind of men and women will be needed as leaders under the new regime. The first steps of this reconstruction will have to be carried on by the present college graduates, and the coming generation will have to be educated in accordance with the newly laid principles of justice and brotherhood, and with sound principles of scientific engineering.

One important direct contribution of the war to the problem of education has been the introduction of elaborate psychological tests for analyzing a person's intelligence, fitness and caliber for a particular kind of work. Some leading universities have either introduced this system to test their students, or are planning to use it in addition to regular examinations. This is only a beginning towards a great new principle, namely that of fitting education to the individual, instead of trying to fit every individual to the same stereotyped courses of instruction.

If there is a recommendation that the retiring committee cares to make to its successors, it is that the new committee should add its influence to the general acceptance of the sound principle that the principal purposes of education are self-realization, inspiration for co-operative service, and the development of intelligence and moral sense, rather than an indiscriminate cramming with undigestable information. Psychological tests made before, during, and after the college course are among the first steps in this direction, and the new committee might well devote its effort to an adaptation of such tests for the needs of electrical and mechanical engineering.

V. KARAPETOFF, *Chairman.*

To be presented at the Pacific Coast Convention of the American Institute of Electrical Engineers, Los Angeles, Cal., September 18-20, 1919.

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ORDER AND AMPLITUDE OF HARMONICS IN VOLTAGE WAVE FORMS WITH INDICATING INSTRUMENTS

BY LESLIE F. CURTIS

ABSTRACT OF PAPER

The author presents a method for the determination of the order and percentage of the various components of an alternating wave of e. m. f., using indicating meters and other inexpensive apparatus.

Two examples are given. Oscillograms are included to show interesting phenomena and to check the results of the calculations.

The value of so-called standards for the indication of wave form is questioned.

INTRODUCTION

MANY writers have discussed the relative merits of various combinations of resistance, inductance and capacitance when used as devices for indicating the deviation of alternating wave forms from the sine curve. They have also defined certain terms such as form factor[1], deviation factor, distortion factor[2], etc., applicable to the above devices when used with indicating meters as standards[3]. (They have, however, failed to show any method by which the order and amplitude of the various harmonics might be obtained by indicating meters.) Each of the proposed standards is also open to the objection that the result obtained by its use is entirely dependent upon the order of the harmonics in question and upon the size of the reactances used.

The maximum distortion, which, in practise, might result from the resonance of a certain harmonic in a long transmission line with distributed inductance and capacity, would be produced by such devices in test only by chance. It is, however, only this resonant condition for the higher harmonics that can cause disturbances which can be charged to generator wave

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[1] See references at end of paper.

form. In the absence of oscillograms, it is therefore necessary to produce resonance of the various harmonics generated within the machine before its worst behavior can be predicted.

In making an oscillographic study of the charging currents for condensers of various sizes from the same source of alternating current it was found that the current wave forms varied greatly with the size of the condenser used. The ratio of the apparent reactance to the true reactance of the same condenser when supplied with a sine wave of voltage at the same frequency, as suggested by a previous writer[4], likewise depended upon the size of the condenser. It was also found that the resistance and inductance of the generator circuit had a decided effect on the indications. A method was then developed which

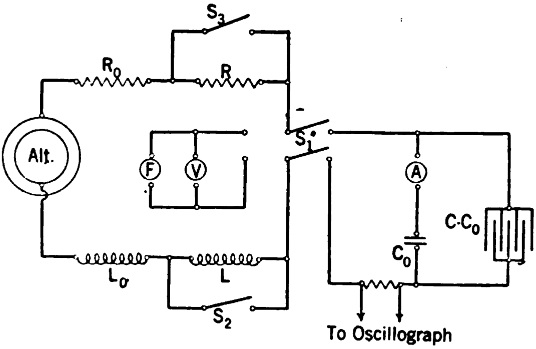

Fig. 1

gave a solution for the order and amplitude of the harmonics present in a given form from the readings obtained with inexpensive indicating meters and other apparatus.

It is the purpose of this paper to present this solution together with two examples of its use with oscillograms taken to show the various wave forms of current and voltage. The method outlined below gives no indication of the relative phase positions of the components and therefore no accurate indication of the maximum value of the resultant wave. In figuring the maxima of voltage or current waves the relative phase position is important only for the lower harmonics, the third and fifth. Thus for most purposes, the phase position of the components is not required and their order and percentage is a sufficient indication of the character of the wave.

METHOD

The method is that of obtaining resonant conditions for the nth harmonic in the generated voltage by several separate adjustments of inductance and capacitance in series with a certain amount of protective resistance. When resonance has been obtained, a second reading is taken with added series resistance.

The diagram of the connections used is shown in Fig. 1. The alternator supplying the wave to be tested is assumed to have an inductance L_0 and a resistance R_0. Resistance R and inductance L may be added to the circuit at will by means of switches S_2 and S_3. V and F indicate a voltmeter and frequency meter connected to the machine by throwing switch S_1 to the left. On throwing S_1 to the right an adjustable condenser $C - C_0$ is connected in the circuit. In parallel with this is a small fixed condenser C_0, the current in which may be measured by a small hot-wire meter A of negligible resistance. C is therefore the total capacitance.

For a given initial voltage and frequency the resonant points for the harmonics are indicated by a maximum deflection of meter D. If R_0 is not sufficient for protection of the condenser from abnormal voltages at resonance, more resistance may be added and considered as a part of the generator. If L_0 is not large enough to produce resonance of the lower harmonics with the amount of capacitance C available, more inductance may be added and considered as a part of the generator.

The calculation consists of two parts; the determination of the order of the harmonics present and the calculation of their amplitude. Table I gives a summary of the notation used in the calculations.

TABLE I—NOTATION

L	Known inductance.
R	Known resistance.
C_0	Known fixed capacitance.
$C - C_0$	Known adjustable capacitance.
C	Total capacitance.
C_1, etc.	Particular value of C.
ω	Angular velocity of fundamental wave.
n	Order of harmonic.
e_m	Effective nth harmonic in generated voltage.
P_m	Percentage of nth harmonic in terms of fundamental

E	Effective value of resultant generated voltage.
i_m	Effective value of nth harmonic in current.
I	Effective value of resultant current.
D	Deflection of hot-wire meter.
k	Calibration constant for A (See Fig. 13).
r_m	Resistance of circuit to nth harmonic.
x_m	Reactance of circuit to nth harmonic.

ORDER OF THE HARMONICS

The order of the harmonics present may be found from the values of capacitance, C_1 and C_2, necessary to produce resonance with and without the known inductance L in series.

In the first case

$$L_0 n \omega + L n \omega = \frac{1}{C_1 n \omega} \tag{1}$$

in the second

$$L_0 n \omega = \frac{1}{C_2 n \omega} \tag{2}$$

from which

$$n = 1/\omega \sqrt{1/L \,(1/C_1 - 1/C_2)} \tag{3}$$

If the result is not exactly a whole number it may be corrected as it is known that n must be an integer and probably odd. If another harmonic is present, its order may be determined in the same way from new adjustments of capacitance, C_3 and C_4, with and without the inductance L. An alternative method is to continue the curve upon which C_1 or C_2 produced resonance after one of the harmonics has been determined and take one additional reading of capacitance for the resonance of the other harmonic.

In this case

$$L_0 \omega = \frac{1}{C_2 n^2 \omega} \tag{4}$$

and

$$L_0 n^1 \omega = \frac{n^1}{C_2 n^2 \omega} = \frac{1}{C_4 n^1 \omega} \tag{5}$$

from which

$$n^1 = n \sqrt{C_2/C_4} = n \sqrt{C_1/C_3} \tag{6}$$

AMPLITUDE OF THE HARMONICS

Having found the order of the harmonics present it is easy to determine their amplitude by taking additional readings of the current-squared meter with a known resistance inserted in the circuit and with the capacitance adjusted for the resonance of the harmonic in question.

In order to introduce no errors due to current in circuits in parallel with the capacitance and to necessitate no correction therefor, no voltmeter or other device should be connected when the readings of the hot-wire meter are taken.

For resonance of the nth harmonic

$$L_0\, \omega = \frac{1}{C_2\, n^2\, \omega} \tag{4}$$

and

$$i_m = e_n / r_n \tag{7}$$

$$i_1 = \frac{e_1}{\sqrt{r_1^2 + \left(\frac{1}{C_2\, n^2\, \omega} - \frac{1}{C_2\, \omega} \right)^2}} \tag{8}$$

$$i_3 = \frac{e_3}{\sqrt{r_3^2 + \left(\frac{3}{C_2\, n^2\, \omega} - \frac{1}{3\, C_2\, \omega} \right)^2}} \tag{9}$$

It will be noted that the resistance of the circuit is assumed to depend upon the frequency of the harmonic. In practise it is shown that the resistance increases with the frequency. In most practical cases the resistances r_1, r_3, etc., are so small compared to the other terms under the radical that they may be neglected.

Therefore

$$i_1 = \frac{e_1}{\frac{1}{C_2\, n^2\, \omega} - \frac{1}{C_2\, \omega}} = \frac{e_1}{x_1} \tag{10}$$

and

$$i_3 = \frac{e_3}{\frac{3}{C_2\, n^2\, \omega} - \frac{1}{3\, C_2\, \omega}} = \frac{e_1\, P_3}{x_3} \tag{11}$$

But

$$I = \sqrt{i_1^2 + i_3^2 + \ldots .\, i_m^2 + \ldots .} \tag{12}$$

therefore

$$I = e_1 \sqrt{\frac{1}{x_1^2} + \frac{P_3^2}{x_3^2} + \dots \frac{P_n^2}{x_n^2} + \dots} \qquad (13)$$

The resultant voltage E is

$$E = \sqrt{e_1^2 + e_3^2 + \dots e_n^2 + \dots}$$

$$= e_1 \sqrt{1 + P_3^2 + \dots P_n^2 + \dots} \qquad (14)$$

and when no harmonic exceeds 10 per cent of the fundamental, e_1 may be replaced by E with less than 1 per cent error.

Now

$$I^2 = \frac{K D C_2^2}{C_0^2} \qquad (15)$$

therefore

$$\frac{K D C_2^2}{E^2 C_0^2} = \frac{1}{x_1^2} + \frac{P_3^2}{x_3^2} + \dots \frac{P_n^2}{r_n^2} + \dots \qquad (16)$$

When a resistance R is placed in series a new reading D^1 is obtained and the corresponding equation is

$$\frac{K D^1 C_2^2}{E^2 C_0^2} = \frac{1}{x_1^2} + \frac{P_3^2}{x_3^2}$$

$$+ \dots \frac{P_n^2}{(r_n + R)^2} + \dots \qquad (17)$$

therefore

$$P_n^2 = r_n^2 \left(\frac{K D C_2^2}{E^2 C_0^2} - \frac{1}{x_1^2} - \frac{P_3^2}{x_3^2} - \dots \right) \qquad (18)$$

and

$$P_n^2 = (r_n + R)^2$$

$$\left(\frac{K D^1 C_2^2}{E^2 C_0^2} - \frac{1}{x_1^2} - \frac{P_3^2}{x_3^2} - \dots \right) \qquad (19)$$

Now usually all terms except those containing constants of the fundamental and the nth harmonic are negligible, therefore

$$P_n^2 = r_n^2 \left(\frac{K D C_2^2}{E^2 C_0^2} - \frac{1}{x_1^2} \right) \qquad (20)$$

and

$$P_n^2 = (r_n + R)^2 \left(\frac{K D^1 C_2^2}{E^2 C_0^2} - \frac{1}{x_1^2} \right) \qquad (21)$$

from which numerical values of r_n and P_n may be obtained. If the other terms are appreciable, an approximate solution may be made by equations (**20**) and (**21**) for all of the harmonics and then corrected by using equations (**18**) and (**19**).

It is suggested that if a calibrated condenser is not available, that the adjustments be made for the current maxima and that the corresponding capacitance be measured on a sine wave before changing the condenser setting. If no adjustable condenser is available, a fixed condenser and calibrated inductance may be substituted. The equations should then be modified to use inductance as the abscissa of the resonance curves.

Example 1: The open circuit wave form of a delta-connected alternator, 1200 rev. per min., 220 volts, run at normal speed but at 100 volts, is shown by the oscillogram in Fig. 2. The resonance curves for this machine by the above method without and with the known inductance L in series are shown in Fig. 3.

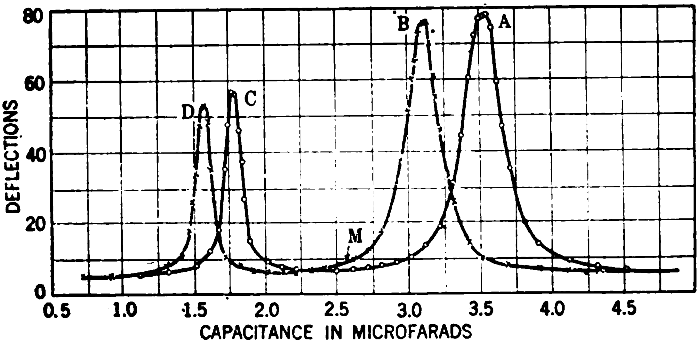

FIG. 3

The inductance L, when measured separately on a 180-cycle wave gave a reactance of 12.6 ohms, and therefore had an inductance of 0.0111 henry. During the test an additional inductance of unknown value was permanently connected in the circuit. C_0 was 0.72 microfarads.

a. Order of the Harmonics:

Maximum points A and B, in Fig. 3, corresponding to 3.53 and 3.11 microfarads, are evidently due to the same harmonic. The equation for the determination of its order is (**3**).

Substitute and $n = \dfrac{1}{2\,\pi\,60}\sqrt{\dfrac{1}{.0111}\left(\dfrac{10^6}{3.11} - \dfrac{10^6}{3.53}\right)}$

from which n equals 4.9 and therefore indicates the fifth harmonic.

Maximum points C and D, at 1.78 and 1.57 microfarads in Fig. 3 are due to the presence of another harmonic. A similar solution to that above gives a value of 6.9 for n and therefore indicates the seventh harmonic.

An alternative solution is, since we know that point A is due to the fifth harmonic,

$$n^1 = 5\sqrt{\frac{3.53}{1.78}} = 7.0$$

From these solutions it is therefore known that resonance points A and B are due to the fifth, and points C and D, to the seventh harmonic.

b. Amplitude of the Harmonics:

The readings for the determination of the amplitude of the above harmonics are given in Table II. Consider the conditions for point A.

From equation (**4**),

$$L_0\,\omega = \frac{10^6}{3.53 \times 5^2 \times 2\,\pi\,60} = 30 \text{ ohms}$$

$$\frac{1}{C_2\,\omega} = \frac{10^6}{3.53 \times 2\,\pi\,60} = 749 \text{ ohms}$$

$$x_1 = 749 - 30 = 719 \text{ ohms}$$

Substitute in equation (**20**) and

$$P_5^2 = r_5^2\left(\frac{0.01214 \times \overline{3.53}^2}{\overline{100}^2 \times \overline{0.72}^2} - \frac{1}{\overline{719}^2}\right)$$

Likewise for point A^1, when a resistance of 2.66 ohms is placed in series, substitute in equation (**21**) and

Solving

$$P_5^2 = (r_5 + 2.66)^2\left(\frac{0.00713 \times \overline{3.53}^2}{\overline{100}^2 \times \overline{0.72}^2} - \frac{1}{\overline{719}^2}\right)$$

Solve and r_5 equals 7.9 ohms and P_5 equals 4.1 per cent.

Points B and B^1 give similar results, 9.1 ohms and 4.1 per cent.

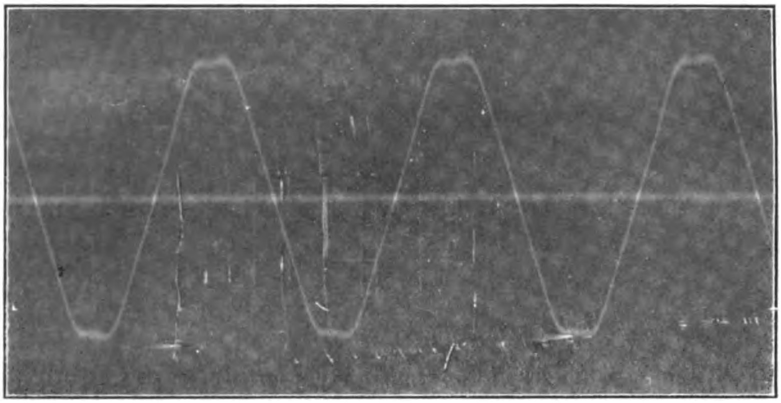

FIG. 2—OPEN CIRCUIT VOLTAGE—EXAMPLE 1 (EFFECTIVE VALUE, 100 VOLTS)

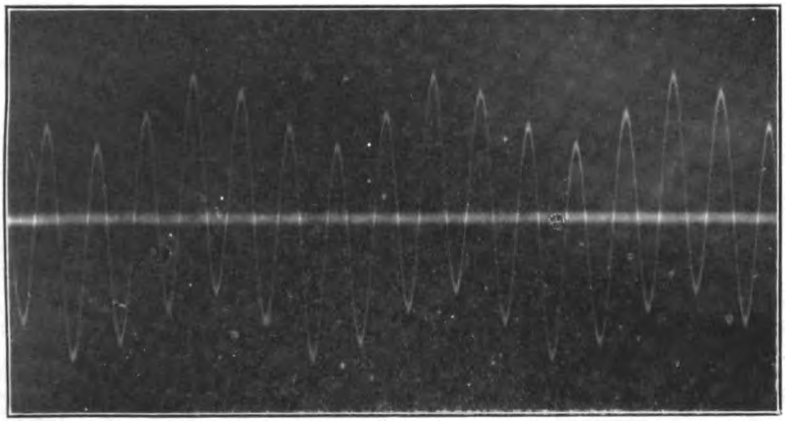

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FIG. 4—CHARGING CURRENT—POINT A, EXAMPLE 1 (EFFECTIVE VALUE, 0.54 AMPERES)

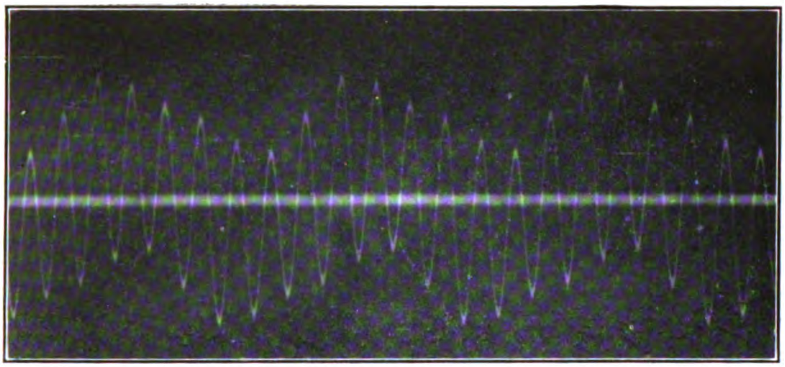

FIG. 5—CHARGING CURRENT—POINT C—EXAMPLE 1 (EFFECTIVE VALUE, 0.24 AMPERE)

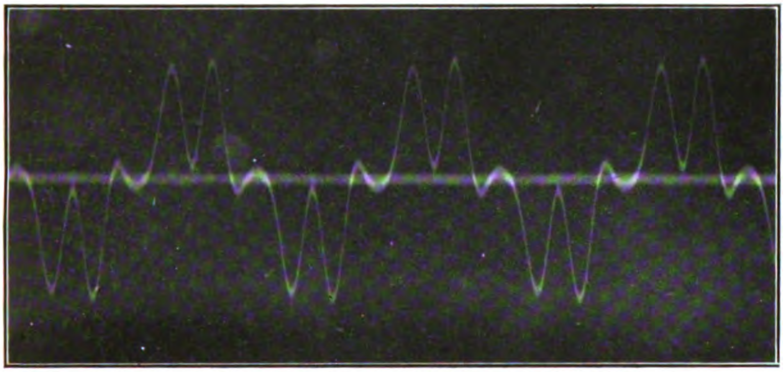

FIG. 6—CHARGING CURRENT—POINT M—EXAMPLE 1 (EFFECTIVE VALUE, 0.15 AMPERE)

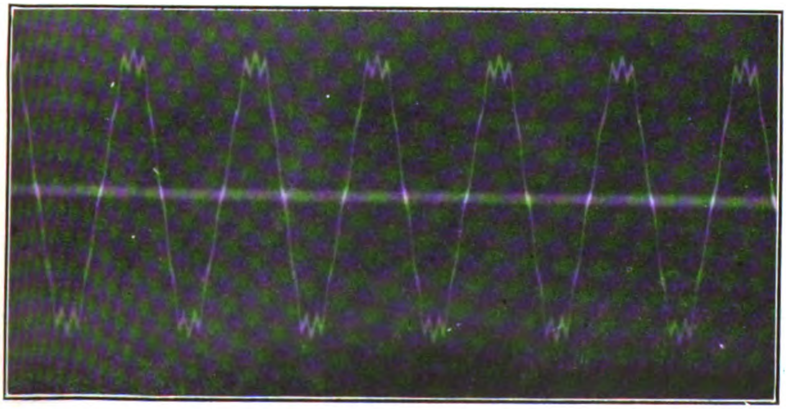

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FIG. 7—OPEN CIRCUIT VOLTAGE—EXAMPLE 2 (EFFECTIVE VALUE, 100 VOLTS)

Solving in the same way for the constants for the seventh harmonic from the values for points *C* and C^1 and r_7 equals 9.7 ohms and P_7 equals 1.7 per cent.

TABLE II
CRITICAL VALUES FOR EXAMPLE 1

Point	*C*	C_0	*R*	*D*	*kD*	*n*	*I*
A	3.53	0.72	0.00	78.0	0.01214	5	0.540
A^1	3.53	0.72	2.66	44.0	0.00713	5	0.415
B	3.11	0.72	0.00	76.0	0.01183	5	0.470
B^1	3.11	0.72	2.66	46.0	0.00745	5	0.373
C	1.78	0.72	0.00	57.0	0.0091	7	0.236
C^1	1.78	0.72	2.66	36.0	0.0059	7	0.190
D	1.57	0.72	0.00	53.0	0.00848	7	0.201
D^1	1.57	0.72	2.66	35.0	0.00574	7	0.165
M	2.62	0.72	0.00	10.0	0.0018	5 & 7	0.149

From points *D* and D^1, the corresponding values are 10.8 ohms and 2.1 per cent.

Oscillograms were taken to check the above results and to show the charging current for the various total capacitances. Fig. 2 is an oscillogram of the no-load voltage of the machine and is the true generated wave form of the machine as no capacitance was connected and the resistance was at least ten times as great as the reactance of the circuit to the seventh harmonic. An analysis of this wave gives 3.5 per cent of the fifth, and 1.6 per cent of the seventh harmonic, no others being appreciable.

Fig. 4 is the wave of charging current (0.540 ampere) for point *A* and shows the predominance of the fifth harmonic. Fig. 5 is a similar curve of charging current (0.236 ampere) for point *C* showing the seventh harmonic. Fig. 6 is the wave of charging current (0.149 ampere) for point *M* corresponding to 2.62 microfarads, Fig. 3 showing the reduction in the amplitude of the harmonics in current and the beats due to both fifth and seventh harmonics.

The resistance of the circuit used was measured with direct current and found to be 5.2 ohms for points *A* and *C*, and 6.2 ohms for points *B* and *D*. The solutions given above show that the resistance to the higher frequencies was very materially increased.

A summary of all of the above calculated data is presented in Table III.

Example 2: The machine used for this test was a synchronous motor, 1800 rev. per min., 110 volts, run as a generator at 100 volts. The open-circuit wave form of this machine is shown in Fig. 7, which upon analysis gives 3.5 per cent of the fifth, 1.4 per cent of the seventh, 7.0 per cent of the eleventh and 2.5 per cent of the thirteenth harmonics.

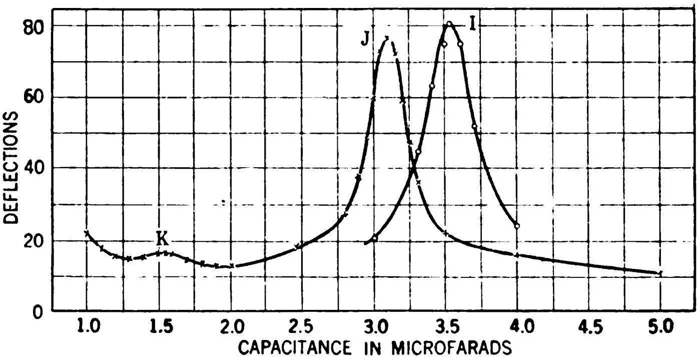

FIG. 8

Unfortunately the machine was fitted with carbon brushes, the resistance of which varied with the current density, so that no check could be made of the above percentages by the method described. It was, however, possible to solve for the order of the harmonics which are indicated in the resonance curves

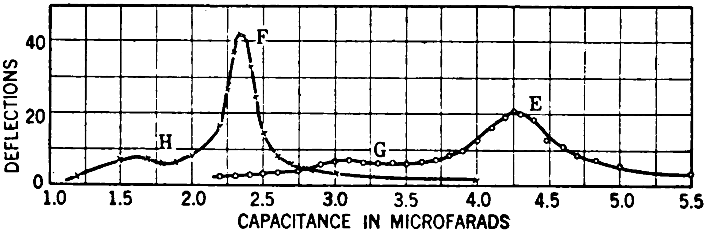

FIG. 9

shown in Fig. 8 and Fig. 9. In Fig. 8 a large unknown inductance is connected in the circuit to make possible the resonance of the lower harmonics (points *I*, *J*, *K*) with small capacitances. This was omitted in taking the curves of Fig. 9.

In Fig. 8 points *I* and *J*, corresponding to 3.52 and 3.10 microfarads, show the resonance of a harmonic without and

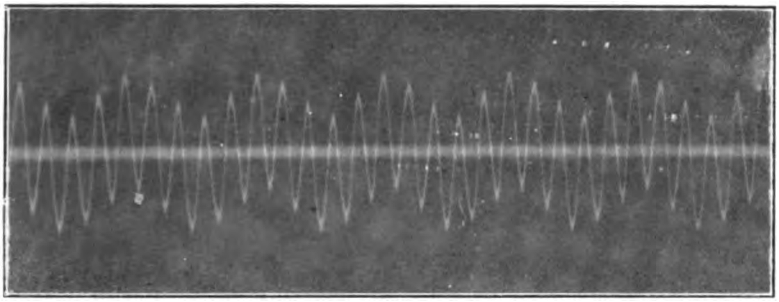

FIG. 10—CHARGING CURRENT-POINT—EXAMPLE 2 (EFFECTIVE VALUE, 0.34 AMPERE)

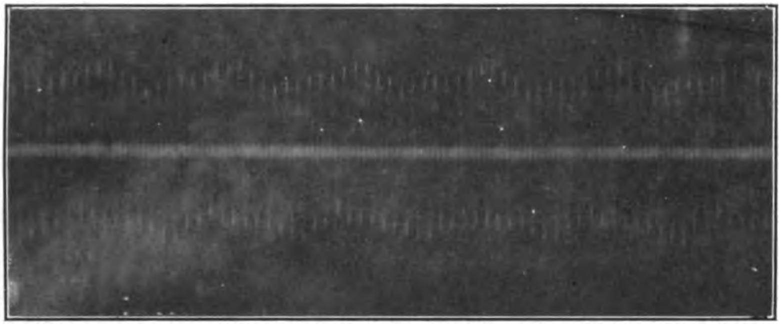

FIG. 11—CHARGING CURRENT—POINT F—EXAMPLE 2 (EFFECTIVE VALUE, 0.97 AMPERES)

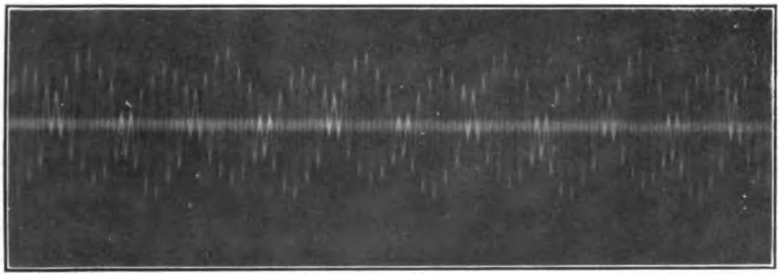

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FIG. 12—CHARGING CURRENT—POINT H—EXAMPLE 2 (EFFECTIVE VALUE, 0.31 AMPERES)

with the known inductance L in series. A calculation shows this harmonic to be the fifth. Point K, corresponding to 1.55 microfarads is on the same curve with point J (3.10 microfarads) and therefore indicates the seventh harmonic. An oscillogram of the charging current at point I (0.342 ampere) is shown in Fig. 10. In the above C_0 was 1.0 microfarad.

TABLE III
CALCULATED VALUES FOR EXAMPLE 1

Points	n	r_n	R	Mean P_n	P_n by Oscillograph
A–A^1	5	7.9	5.2	4.1	3.5
B–B^1	5	9.1	6.2		
C–C^1	7	9.7	5.2	1.9	1.6
D–D^1	7 1	10.8	6.2	100.0	100.0

TABLE IV
CRITICAL VALUES FOR EXAMPLE 2

Point	C	C_0	D	kD	n	I
E	4.27	0.20	21.0	0.0035	11	1.260
F	2.34	0.20	42.5	0.0069	11	0.971
G	3.10	0.20	7.5	0.0013	13	0.559
H	1.65	0.20	8.0	0.0014	14	0.309
I	3.52	1.00	81.0	0.01255	5	0.394
J	3.10	1.00	77.0	0.1020	5	0.340
K	1.55	1.00	16.5	0.0028	7	0.082

Similar solutions for points E and F, corresponding to 4.27 and 2.34 microfarads, and points G and H, corresponding to 3.10 and 1.65 microfarads, as shown in Fig. 9, give indications of the presence of the eleventh and thirteenth harmonics. An oscillogram of the charging current at point F (0.971 ampere) is shown in Fig. 11 and that for point H (0.309 ampere), in Fig. 12. In the above C was 0.2 microfarads. Fig. 12 is particularly interesting since it shows the beats due to the eleventh and thirteenth harmonics even when the thirteenth is in resonance, that is, the eleventh is not, in this case, negligible. This might also be surmised from the shape of the resonance curve near point H in Fig. 9.

A tabulation of the readings at the critical points in the above example is given as Table IV.

A calibration curve of the hot-wire meter is given in Fig. 13 so that further calculations may be made if desired.

CONCLUSIONS

It is practicable to test for the order and amplitude of the harmonics in any alternating wave of voltage by the use of inexpensive indicating meters, a known inductance and an adjustable condenser without knowing the resistance and inductance of the machine itself.

A small change in the capacitance or inductance of any of the so-called wave form standards may result in a great change in the current in the circuit, making such devices unreliable.

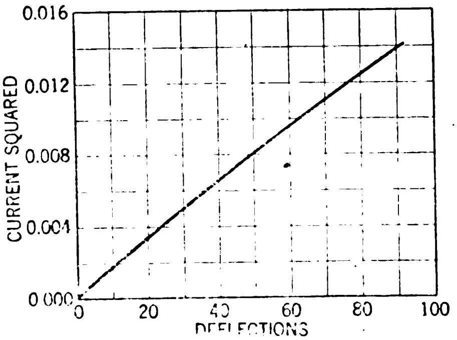

Fig. 13

The resistance of any circuit may change with the frequency of the harmonics present and this fact may introduce an error in making measurements with any of the so-called standards.

REFERENCES

1. *Form Factor and Its Significance*, by F. Bedell, TRANS. A. I. E. E., Vol. XXXIV, 1915, pp. 1135–1142.

2. *Distortion Factors*, by F. Bedell, TRANS. A. I. E. E., Vol. XXXIV, 1915, pp. 1143–1157, and "*An Analytical and Graphical Solution For Non-Sinusoidal Alternating Currents*, by F. M. Mizushi, TRANS. A. I. E. E., Vol. XXXIV, 1915, pp. 1159-1170.

3. *Characteristics of Admittance Type of Wave Form Standards*, by F. Bedell, TRANS. A. I. E. E., Vol. XXXV, 1916, pp. 1155-1170.

4. *A Proposed Wave Shape Standard*, by C. M. Davis, TRANS. A. I. E. E., Vol. XXXII, 1913, p. 775.

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THEORY OF PROBABILITIES APPLIED TO FAILURES OF SUSPENSION INSULATORS

BY L. M. KLAUBER

Abstract of Paper

Nothwithstanding the recent improvements in porcelain insulators, failures are sufficiently common so that allowance must be made for them. A certain factor of safety is required, in the shape of extra insulation, to provide for the electrical unreliability of the insulators themselves aside from conditions of abnormal operating stresses.

There are a wide variety of operating conditions which affect the amount of over-insulation required, and after having found the minimum number of insulators per string required for any given operating conditions the author points out a method of determining the amount of extra insulation desirable from an insurance standpoint according to the law of probabilities. Equations are developed from which the probability of failure for any given case or the ratio between such probabilities for any pair of cases may be determined directly. A numerical example is also given which shows the development of the theory of minimum annual cost for combined mechanical and electrical failures.

At THE present time there exists a diversity of views as to the primary cause of failure of suspension insulators of the disk type. Extensive investigations are being carried forward to determine the causes of failure in order that such causes may if possible be eliminated in manufacture. Unfortunately, however, while recent types have shown a notable improvement over those produced but a few years ago, failure is still sufficiently common to require allowance therefor in all specifications covering new lines. That is, it is not advisable in any construction to limit the number of insulators in a string to a quantity just sufficient to withstand the line pressure under service conditions, and thus cause failure if one member of the string fails. On the contrary, under present conditions, it is good practise to allow a certain proportion of extra insulators, a factor of safety required by the electrical unreliability of the insulators themselves, rather than by the necessities of abnormal operating stresses.

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Obviously, the degree of over-insulation which should be indulged in depends on a variety of factors which cannot be directly expressed in mathematical terms. It is necessary to consider the first cost of the extra insulation and the fixed charges on such cost; also the counter-balancing expense involved in shut-downs, both prearranged and unforeseen. The requirements of continuity of service, and the availability of duplicate lines and stand-by power sources, have an important bearing on design. Also there is the factor of climatic conditions, the occurrence of lightning, temperature ranges, both daily and seasonal, humidity, the frequency of cleansing rains, the presence of salt fogs, wind-carried dust or the fumes of industrial plants. The nature of the line supports must be considered; we must know if the towers are of steel or wood, and if of wood, whether the support ends of the strings are electrically connected together. The transformer connections, whether with grounded or isolated neutral, must be noted. Mechanical stress is of importance. These, and many other conditions all affect greatly the degree of over-insulation necessary or advisable, and show why in some cases a 66-kv. line requires only three units per string, while under other conditions seven may be insufficient.

But having determined the minimum number of units per string required for a given voltage and set of operating conditions, it becomes interesting to investigate the value of additional units, purely from an insurance standpoint; and this investigation may be best performed by calculations of the chances of failure under the laws of probability. The physical condition under which the line operates will of course affect the rate of failure, but these conditions may be grouped and allowed for in the depreciation rate assumed.

In order to permit employment of the simpler laws of probability, it is necessary to assume that the successive failure of units in any string does not increase the liability to individual failure of the remaining members of that string until a minimum is reached which permits complete breakdown. At first glance this appears a most incorrect assumption, since, after the failure of one unit it is evident that there is an increased electrical strain upon the balance. Nevertheless, it is the belief of many investigators that the particular type of electrical failure which is today one of the great difficulties of transmission line operation, is in small degree hastened by increased electrical duty. In fact this opinion seems borne out by the relative frequency of occurrence of multiple failures which is usually found to be in the ratio expected under the laws of probability governing independent events. Furthermore, it has been the experience of some companies that insulator failures in lines out of service or in stocks held in the storeroom, have been in the same proportion as those experienced by units of the same lot in active use. So that while in some cases successive failures of members of the same string may not be considered independent events, in general we will not go far wrong in so considering them.

In consideration of the general case of insulator strings, consisting of any number of identical units, we may utilize the general expression of the probability of independent events happening or not happening:

$$P = p^n + n \,.\, p^{n-1} q + \frac{n\,(n-1)}{1\,.\,2} p^{n-2} q^2 \,.\,.\,.\,.\,.\,.\,.\,.\,.\, + p^{n-n} q^n \qquad (1)$$

in which p is the probability of an event happening out of a single trial, $q = 1 - p$ is the probability that it will not happen and n is the number of trials under consideration. In this expression the first term is the probability that the event will happen n times consecutively or every trial, the second that it will happen $n - 1$ times out of n, the third $n - 2$ times out of n, etc. The probability of an event happening exactly r times out of n will be represented by the $(n - r + 1)$th term in the above equation, or

$$P_r = \frac{n\,!}{r\,!\,(n-r)\,!} p^r q^{n-r} \qquad (2)$$

and the probability of an event happening *at least* r times out of n trials is the summation of the terms up to and including the $(n - r + 1)$ th term.

$$\text{Thus:} \quad P_R = p^n + n \,.\, p^{n-1} q + \frac{n\,(n-1)}{1\,.\,2} p^{n-2} q^2 \,.\,.\,.\,.\,.\, + \frac{n\,!}{r\,!\,(n-r)\,!} p^r q^{n-r} \qquad (3)$$

Translating these equations to terms of suspension insulator failures, we may let n represent the number of units per string.

Likewise assume that if r units fail, a line failure will result, but that if less than r units fail the remaining insulation will be sufficient to "hold" the line and failure will not result. Then if $p =$ the probability of individual insulator failure (electrical) based on experimental data or experinece with insulator depreciation, equation (**3**) gives directly the probability of line failure per string of insulators installed and the total probability of line failure will be found by multiplying the chances per string (P_R) by the number of strings (N) in the line or

$$P_N = N\,P_R \tag{4}$$

From equations (**3**) and (**4**) we may determine directly the probability of failure for any given case, or the ratio L between such probabilities for any pair of cases.

It will be noted that where p is small compared with q, as with depreciations of the order under consideration, only the $(n - r + 1)$ th term is of importance, the preceding terms being of such small value comparatively that to consider them is to assume an accuracy not warranted by the original data. We have, therefore, as a simplified equation of the chances of electrical line failure:

$$P_N = N \frac{n\,!}{r\,!\,(n-r)\,!}\,p^r\,q^{n-r} \tag{5}$$

Numerical examples are more easily solved, using this equation in the equivalent form:

$$P_N = N \frac{n\,!}{r\,!\,(n-r)\,!}\,\frac{(q/p)^{n-r}}{(1/p)^n} \tag{6}$$

as this will usually involve powers of integers rather than fractions.

The application of formula (**6**) to specific cases will often give interesting results. Fig. 1 indicates the range of example values of P_R plotted for three sets of values of $n - r$ and p Because of the minute values of P_R at the higher values of n. the curves are plotted in terms of $\log 1/P_R$. Naturally where the safety factor $\frac{n}{n-r}$ is large $1/P_R$ attains values which are of little practical interest.

Fig. 2 is a diagram for the solution of the equation

$$P_R = \frac{n\,!}{r\,!\,(n-r)\,!}\,p^r\,q^{n-r}$$

From this diagram values of the probability of failure per string can be quickly determined, with reasonable exactitude. The solution is based on a straight line diagram deduced from this equation in the form:

$$\log 1/P_R = n\,[2 - \log(100 - s)\,] + r \log \frac{100 - s}{s} - \log\left[\frac{n\,!}{r\,!\,(n - r)\,!}\right]$$

where $s = 100\,p$ or the depreciation in per cent.

Of equal interest with the probability of failure in any specific case is the determination of the ratio L between the probabilities of failure in related cases and in particular the decrease in probability of failure (or insurance) derived from the addition of extra insulators. In determining the ratio between probabilities it will be sufficiently accurate to employ the approximate formula (**5**) and noting that in any assumed case having to do with a specific line, the quantity $n - r$, that is, the number of insulators at which failure will occur is constant, it may be readily shown that

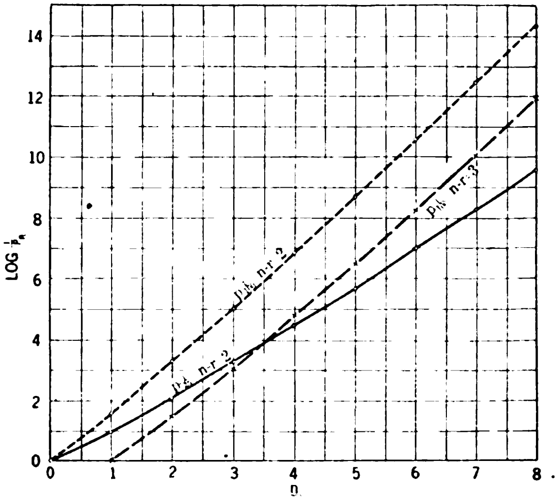

FIG. 1—PROBABILITY OF ELECTRICAL FAILURE PER INSULATOR STRING—EXAMPLE VALUES OF P_R

$$L = \frac{n_1\,(n_1 - 1)\,(n_1 - 2)\,.\;.\;.\,(n_2 + 1)}{r_1\,(r_1 - 1)\,(r_1 - 2)\,.\;.\;.\,(r_2 + 1)}\;p^{n_1 - n_2} \qquad (7)$$

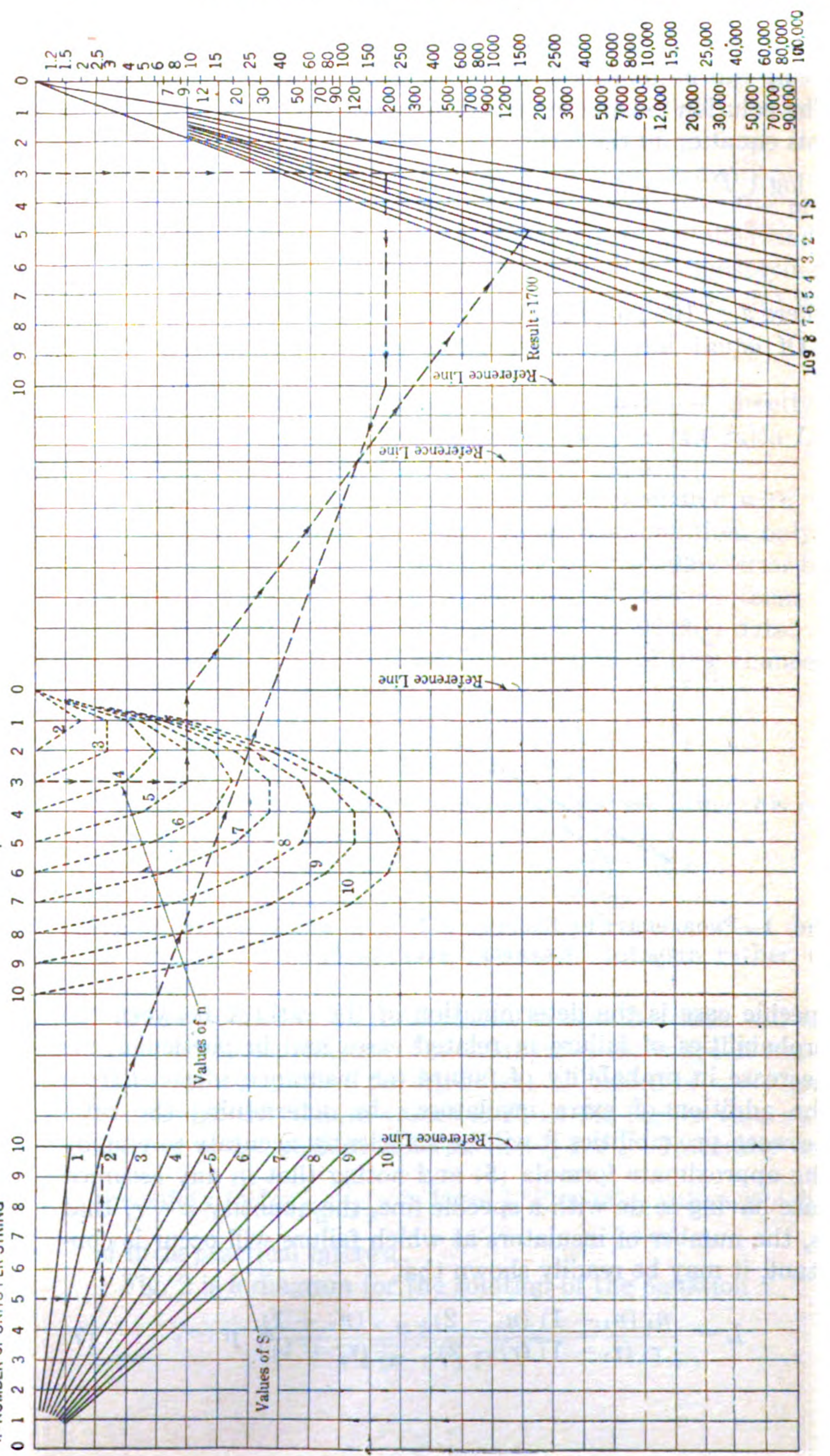

Fig. 2—Diagram for Graphical Solution of $P_R = \frac{n!}{r!\,(n-r)!}\,p^r q^{n-r}$ = Probability of Failure per String per Year

n = number of units per string; r = number of units per string that must fail to result in line failure; S = annual depreciation in per cent = $100p$.

Example worked out, n = 5, r = 3, S = 4%. Result $1/P_R$ = 1660

in which the subscripts 1 and 2 indicate the two conditions assumed as to number of units per string.

It is evident that in most practical cases $n_1 - n_2 = 1$ or 2 since usually it will be desired to determine the reduction in probability of failure secured by increasing a string by one or two insulators. In Table I will be found values of

$$C_L = \frac{\dfrac{n_1\,!}{r_1\,!\,(n_1 - r_1)\,!}}{\dfrac{n_2\,!}{r_2\,!\,(n_2 - r_2)\,!}}$$

for $n_1 - n_2 = 1$ and varying values of $n - r$, and since when $n_1 - n_2 = 1$, $L = C_L\,p$, any problem having to do with the insurance derived by the addition of a single unit may be determined directly from the table.

TABLE I—VALUES OF COEFFICIENT C_L for $n_1 - n_2 = 1$ (1 insulator added to string)

$n - r$ Number at which break-down occurs	n_2 = Number of insulators in string before addition of one unit									
	1	2	3	4	5	6	7	8	9	10
1	2	1.5	1.33	1.25	1.2	1.17	1.14	1.12	1.11	1.1
2	..	3	2	1.67	1.5	1.4	1.33	1.29	1.25	1.22
3	..	..	4	2.5	2	1.75	1.6	1.5	1.43	1.37
4	..	..	..	5	3	2.33	2	1.8	1.67	1.57
5	..	..	..	..	6	3.5	2.67	2.25	2	1.83
6	..	..	..	..	..	7	4	3	2.5	2.2
7	..	..	..	..	..	..	8	4.5	3.33	2.75
8	..	..	..	..	..	..	..	9	5	3.67
9	..	..	..	..	..	..	..	..	10	5.5
10	..	..	..	..	..	..	..	..	..	11

Figure 3 shows some example curves plotted from the use of Table I.

In addition to these conclusions as to the insurance derived by adding units to strings of insulators in transmission lines, it may be noted with reference to dead-ends in higher voltage distribution lines, that where a single unit is adequate to normal service, but is subject to failure at the rates to be expected amongst suspension units, that is, of an order of magnitude of from one-quarter of one per cent to 4 per cent per annum, the single unit is no longer to be considered as economically sufficient; for the line reliability will then be only the relatively low reliability of the individual units multiplied by the number of units. With two units the probability of failure is greatly reduced and in a general way it may be said that with lines of sufficient voltage so that line failures almost invariably follow the failure of the principal insulating member at any point of support (that is in lines of 10 kv. and up where subsidiary insulators in the form of wood pins, cross-arms or poles will not withstand normal line voltage) it is never economical to use single suspension units as dead-ends. Even insulators of weaker design (electrically) are in such cases to be preferred in pairs to a single unit, provided that one unit of the weaker pair will withstand normal operating stresses in case of failure of the other. For instance, if the rates of depreciation are 4 per cent for the small units and 1 per cent for the large, the ratio of line failures in the two cases will be $6\frac{1}{4}$ to 1 against the single large unit.

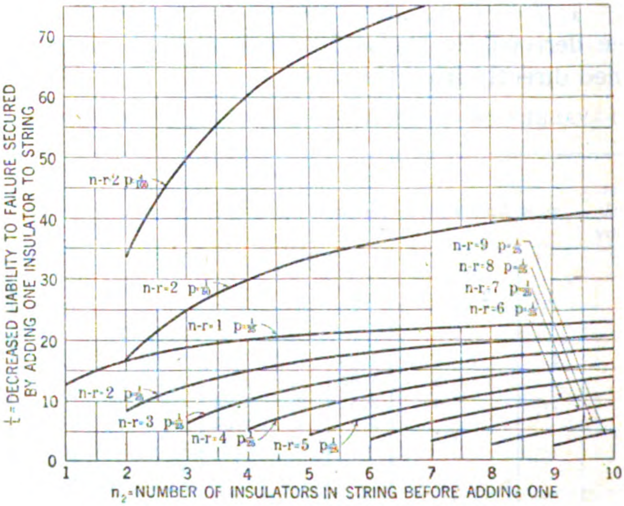

FIG. 3—INSURANCE AGAINST ELECTRICAL FAILURE BY ADDING ONE INSULATOR TO STRING—EXAMPLE VALUES OF L

These considerations likewise show why an insulator string composed of a number of virtually independent units is generally to be preferred to any form of support consisting of a single unit or group of interdependent units.

It may be said that it is difficult to determine $n - r$ or the number of insulators which is one less than will "hold" the line upon which the use of this formula rests. The ordinary 10-in. suspension insulator is usually rated as having a dry flash-over value of 90 kv. and a wet value of 70 kv.; in pairs the corresponding values are respectively 160 kv. and 110 kv. Yet we know from experience that two of these insulators would not stand up on a 66-kv. line under the most favorable conditions for more than a short period. Line surges, weather conditions, etc., all reduce $n - r$, and it is important in choosing a value for $n - r$ in these formulas that the quantity be understood to represent not the number of insulators at which break-down will occur instantly, but rather the number at which break down will occur under normal operating conditions within a short period subsequent to the failure of the $(n - r + 1)$th unit of a string. This break-down may always occur subsequent to surges which are to be periodically expected in any line and if these surges are sufficiently frequent to greatly outnumber the expected string failures, as they will be in almost every practical case, simultaneous failures will not be sufficiently frequent to render the formulas incorrect. The finding of numbers of shattered strings after a total failure is not generally an argument in favor of the occurrence of simultaneous failures, but rather these shattered strings represent previous unexplained momentary failures. Furthermore, the tendency of surges to produce simultaneous failures and thus reduce line outages, is to a certain extent balanced by the original assumption of successive unit failures being entirely independent events, which is not strictly true. In general, it may be said that owing to the difference between test and laboratory conditions, and further because of surges, which tend to give any line a true voltage as regards effects on insulators in excess of its rated voltage, we will not go far wrong in basing $n - r$ on half the wet flash-over rating given by manufacturers to their product. It may be noted from Table I that a variation of one in $n - r$ does not greatly affect the value of L in most practical cases.

As we increase the number of units and thus decrease the chances of electrical failure, we increase the chances of mechanical failure. Mechanical failures are of two general classes,those due to lack of strength or inherent defects in the insulator or its supports, and those due to external causes, such as the malicious use of firearms. Obviously, any mechanical failure means a line failure, particularly at dead-end points where mechanical failures of the first type are most likely to occur.

By mechanical failure is meant the complete breakage of a unit as a means of support. Mechanical failures of the several types which are the initiating causes of electrical break-down (as, for instance, those which follow cyclic temperature changes) but which do not in themselves cause the line to fall, must be considered the equivalent of electrical failures and must be allowed for in the choice of the value of p_e (the probability of electrical failure per unit), since they affect line failures under the same laws. But for true mechanical failures the chance of failure per string is the chance per insulator times the number in the string, or

$$P_m = n\, p_m{}^{*} \qquad (8)$$

or for the whole line

$$P_{Nm} = Nn\, p_m \qquad (9)$$

Since electrical and mechanical failures as above defined are independent and exclusive events, the probability of failure of both kinds is equal to the sum of the probabilities of failure of either kind, or

$$P_{Nt} = N\, n\, p_m + N \frac{n\,!}{r\,!\,(n-r)\,!} p_e{}^r\, q_e{}^{n-r} \qquad (10)$$

This equation may be most easily investigated for the value of n which will give a minimum of annual failures for any set of values of p_m, p_e and r by plotting, particularly as short cuts have been given for determining values of P_{Ne}. But in general we are not as much interested in the value of n which in any case will result in a minimum number of failures. For many values of p_e and p_m this will give impractical or impossible results. What we are interested in is the reduction of cost of service, including all elements of fixed charges, maintenance and depreciation.

Formula (**10**) may be applied to a practical problem in the following manner:

Assume a line containing 1000 insulator strings. Two good insulators in a string will result in a line failure; three will hold the line. It is required to determine whether four or five insulators per string will result in the most economical installation.

Let it be assumed that insulator units in the line as constructed will cost \$3.00 each. The fifth unit is also estimated to cost $3.00, no additional cross-arm length or tower height being required for clearance owing to the extra 5½ in. of length of string. Fixed charges are taken at 12 per cent, this figure including functional depreciation of insulators, but being exclusive of physical depreciation, which is taken care of under maintenance. The cost of replacing an insulator unit which has failed electrically, but which has not resulted in a line failure, is estimated at $5.00, it being assumed that the line is gone over with suitable testing apparatus annually, all defective units being replaced at that time. The cost of field testing insulators is taken at 10c. each. The cost of an unexpected line failure, including location of the failure, replacement of the broken units, loss of business and stand-by plant operation, is taken at $150.00. Naturally, this amount is subject to wide variation, being made up of a number of items, some of which, like the value of continuity of service from a public policy standpoint, cannot be expressed directly in terms of money. In fact it is conceivable that in some cases the cost will be less, but in many cases greatly in excess of the above figure, particularly where service is dependent on a single line and the cost of stand-by energy (if available at all) is considerably in excess of the cost of energy secured over the transmission line. Assume an electrical failure of four per cent per annum, and a mechanical failure (as above defined) of one-fortieth of 1 per cent as an average for units both in suspension and in strain at dead-ends.

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*The subscripts m and e are used hereafter to distinguish between mechanical and electrical failures.

We now have the following tabulation of annual costs:

	Quantity			Amount	
	Four units	Five Units	Unit cost	Four units	Five units
Fixed charges	4000	5000	12% of 3.00	$1,440.00	$1,800.00
Total electrical failures (4%)	160	200	5.00	800.00	1,000.00
Electrical line failures (P_{Ne})	8.85	0.59	150.00	1,327.50	88.50
Mechanical line failures (P_{Nm})	1	1.25	150.00	150.00	187.50
Insulator testing	4000	5000	0.10	400.00	500.00
	Total annual cost			$4,117.50	$3,576.00

It will be noted that all of the above items of cost, with the exception of those due to electrical line failures, vary directly with the number of units in use, and may therefore be grouped. In the above schedule these items total 23.25 per cent of the first cost of the units installed, and the same result would have been secured by taking annual charges at that figure instead of 12 per cent. Summing up the terms of this nature, we have.

$$y = F_c A N n + B N \frac{n\,!}{r\,!\,(n-r)\,!} p_e^{\,r}\, q_e^{\,n-r} \qquad (\mathbf{11})$$

in which y is the total annual cost, F_c is the per cent covering fixed charges and items of maintenance varying directly with the number of units installed and determined as illustrated in the table above, A is the fist cost per unit installed and B the cost per unexpected failure. Differentiating with respect to n and equating to 0 for a minimum we have:

$$F_c A + B \frac{n\,!}{r\,!\,(n-r)\,!} p_e^{\,r}\, q_e^{\,n-r} \left[(n-r)\,! \left(\frac{1}{n} + \frac{1}{n-1} \cdots\cdots\cdots + \frac{1}{n-r+1} \right) + \log_e q_e \right] = 0 \qquad (\mathbf{12})$$

This equation is too involved to be used conveniently in solving for n and it is more practical to determine the value of n which gives a minimum total cost in any case by using Fig. 2 in connection with equation (**11**) and solving by plotting or tabulation. For instance, in the example above discussed we have:

n	$F_c\, A\, N\, n$	$B\, N\, P_R$
3	$2,092.50	$16,595.00
4	2,790.00	1,327.50
5	3,487.50	88.50
6	4,185.00	5.30

A casual inspection shows that $n = 5$ gives a minimum annual cost in this case.

In the utilization of the formulas proposed, it is essential to differentiate between electrical depreciation failures and line condition failures. The first affects the selection of p_e, the second of $n - r$. The first is usually although not invariably characterized by failure by puncture, the latter by failure by flash-over. In some districts, notably along the California coast, climatic and atmospheric conditions are such that any line, regardless of the degree of over-insulation used will ultimately fail by flash-over, if not given continued attention. The gradual accumulation of salt and dust, particularly on the under side of the units, beyond the reach of the infrequent winter rains, will eventually result in flash-over. In other words, as time goes on, if the insulators are not artificially cleaned, r becomes zero and line failures result in great numbers without the occurrence of a single failure of the other type.

It is therefore necessary in considering a problem of this type to note the value which $n - r$ will reach before natural causes, such as a cleansing rain, or some artificial means is used to reduce this quantity to its original value.

On the other hand it should be emphasized that in this discussion the probability p_e of electrical failure is intended to cover those types of failures variously attributed by insulator specialists to porous porcelain, to expansion difficulties induced by cyclic temperature changes or to combinations of the two. In any lot of insulators under a specified set of conditions a certain proportion will become defective, due to these or similar causes, and the balance will remain intact. There is at any given time a reasonably sharp line between the good and the bad; that is to say, between those that will fail when moisture and line conditions are favorable to failure and those that will not. In general, insulators deteriorated in this manner under no circumstances will return to their original quality, although failure may not be instantaneous, and although testing by the several common methods (high-frequency, high-potential and megger) may indicate a variety of degrees of deterioration. But under conditions of incipient failure of the surface leakage type all the individual units will be found uniformly deteriorated (within fairly narrow limits), and in this type of deterioration of condition there is no sharp line between a "good" and a "bad" unit. Furthermore these units may at any time prior to damage by a power arc be returned to their original quality by cleaning. It is evident at once that while failures of the puncture type may be and probably are independent events, failures of the surface leakage type can under no circumstances be so considered. Under flash-over conditions individual units do not act independently.

Although nearly every insulator failure is finally a flash-over there is little practical difficulty in differentiating between the two types of failure. The flash-over due to deteriorated line conditions shows a heavy foreign deposit on the insulator surface. In almost every case the bottom member of the string will be shattered; often the top member also, but rarely an intermediate member. Unbroken units will before cleaning give a zero reading with a megger and a very low flash-over with a high potential test. Subsequent to cleaning, however, unless badly burned by the power arc, they will give as high a megger and flash-over test as when new. Lines subject to difficulties of this kind cannot be tested with a megger in the field even on a clear, dry day, unless each unit is wiped off before test.

In the other type of failure we have the fundamental condition that r units have failed by material depreciation (usually puncture) and the balance $(n - r)$ being unable to hold the line have subsequently flashed-over. The characteristic differentiating this class of failure from the other is the number of punctured units which occur at random throughout the string. Even if subsequently shattered by the power arc they may usually be readily distinguished from units shattered by the other type of failure.

In testing and renewing insulators on the line it is desirable that results be recorded in detail. The distribution of failures between strings, their location in different sections of the same line and the relative frequency of failure of units in corresponding positions in the string, all will be of interest in deducing the causes of failure. It is desirable to know whether bottom, top or intermediate units fail most frequently, and in what ratio; whether units in greater tension at dead-ends fail more frequently than those in suspension; whether units with bolts exposed to the direct rays of the sun fail more frequently than those on the same tower but with bolts toward the north and consequently protected from the sun by the porcelain shells. It is of interest to note whether failures follow hot spells, whether they are decreased by cleansing rains and other effects of the weather. If lines operating under similar conditions contain units differing in manufacture, it is of course important to determine separately the percentage of failures for each type. Also by noting the relative frequency of single and multiple failures, it is possible to determine whether failures follow the laws of probability for purely independent events, as above outlined, or whether successive unit failures are to a certain extent dependent events.

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SOME PROBLEMS IN THE OPERATION OF POWER PLANTS IN PARALLEL

BY E. C. STONE

ABSTRACT OF PAPER

In order to operate two power plants satisfactorily in parallel, the transmission line which ties them together must have sufficient synchronizing power, as well as sufficient carrying capacity. The "synchronizing power" of a line depends upon its resistance and reactance, the bus voltages maintained at its ends, and the maximum kilovolt-amperes it must transmit. The ability of different lines to provide satisfactory parallel operation cannot be measured by any standard which does not take account of all of these factors. Limiting values for "synchronizing power" of lines under various operating conditions are given.

The division of load between two plants in parallel is regulated by steam control; the division of wattless current associated with the load depends upon the voltages generated and may be in proportion to the division of real load, when the difference in voltage at the two busses will vary with the load transmitted, or may be arbitrary so that regardless of the load transmitted, the voltages on the two busses will be maintained constant. The latter plan generally gives better operating conditions on the system as a whole, but creates demands for wattless currents at either or both plants in excess of their normal capacity, and in so doing, involves an additional cost. The excess wattless cross-current so created can be materially reduced by varying the voltage with changes in load transmitted through the use of taps on the line transformers, by inserting additional reactance in the line at light loads, or, when the stations are tied together by several parallel lines, by cutting out one or more lines as the load decreases.

The design of a transmission line involves a consideration of load to be transmitted, voltage, reactance, resistance, losses, and charging current of the line, and of wattless generating capacity at the receiving end of the line. The wattless generating capacity at the end of the line determines how many kilowatts will be transmitted for each ampere of line current, by fixing the power factor of the load transmitted and the voltage at the receiving end of the line. When a line is to be designed for paralleling two plants, it must have sufficient "synchronizing power" to hold the two plants together.

THE advantages to be derived from the operation of all the power plants serving a territory in parallel are many and great. The maximum or peak capacity is increased because of the diversity of the load in different parts of the territory served; small plants with high operating costs are made available for peak service only, without the injurious effects of interruption to service when loading them up and shutting them down; the strain of carrying sharp and sudden peak loads is distributed over the whole generating system; customers in all parts of the system are given the benefits in steady frequency and stability of power supply which come from drawing their power from a source of supply having a capacity vastly greater than their individual requirements.

It is not possible, however, to merely synchronize all the power plants of a system together over any lines that may be available and obtain therefrom all the advantages of parallel operation without experiencing any difficulties. The steam governing devices of the various units at the different plants must be adjusted with respect to each other so as to properly divide the load at all times. The heavy concentration of power in short circuits which results from parallel operation requires that adequate circuit breakers and other protective devices must be installed. The transmission lines used for tying the plants together must have suitable characteristics and sufficient capacity. This paper deals with the latter subject.

When a number of individual machines are operated in parallel in one power plant on a single bus, the impedance in the circuit connecting them is so small as to be quite negligible in its effect on the parallel operation of the machines. When however, two separate power plants are operated in parallel, the transmission line tying them together comes in between the busses, thereby increasing the impedance of the connecting circuit to many times that of a station bus and decreasing its carrying capacity correspondingly. The impedance and carrying capacity of a transmission line thus become very important factors in determining the manner in which the power plants which it ties together will operate in parallel.

The action by which two alternating-current generators connected to a common bus are held in synchronism is commonly understood. If one machine attempts a speed different from that of the other, a difference in phase immediately develops between their voltages, which causes a cross current to flow through the local circuit made up of their armature windings and leads and the bus section between them. Because of the reactance in this circuit, the cross current is of such a phase as to transfer a part of the load carried by the lagging machine over to the leading machine. This in turn causes the former to speed up and the latter to slow down, so that their voltages are brought back into phase and synchronism is maintained.

When two power plants are operated in parallel, the action described above is modified by the insertion of the tie line in the local circuit between generators. The vector diagram for a given set of conditions as to plant voltages and line impedance, is shown in Fig. 1. When the two power plants are exactly in step so that their voltages E and E_2 are in phase, the voltage across the circuit tying them together is e_2, the current I_2 and the power transmitted from station 1 is P_2. The station delivering power to the tie line will be designated as station 1 or the transmitting station, and the station receiving power from the tie line will be designated as station 2 or the receiving station.

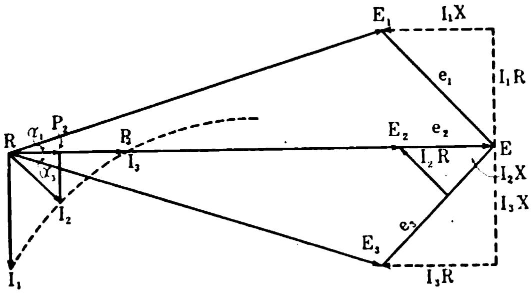


FIG. 1—VECTOR DIAGRAM

E = Voltage at Station 1.
$E_1E_2E_3$ = Voltages at Station 2.
$e_1e_2e_3$ = Voltages across tie line.
$P_1P_2P_3$ = Power delivered to tie line from Station 1.
R = Ristance of tie line.
X = Reactance of tie line.
Station 1 delivers power to line.
Station 2 receives power from line
$X/R = 1 \quad E_2/E_1 = 0.80$

If station 2 speeds up so as to lead station 1 by the angle a_1, the voltage on the tie line is increased to e_1 and the current to I_1, but since I_1 is at right angles to E, the power transmitted from station 1 to station 2 is zero. Thus station 2, by advancing position from position E_2 to position E_1 has taken from station 1 an additional load equal to P_2. On the other hand, if station 2 lags behind the angle a_3, the current becomes I_3 and power P_3, so that station 2 has then dropped an amount of load equal to $P_3 - P_2$ which amount has been taken up by station 1, loading up the tie line still further until a certain critical angle of lag is reached beyond which the load transmitted over the tie line decreases instead of increases.

The curves of Fig. 2 show how the amount of power transmitted—or load transferred—over tie lines having the same resistance, but different reactances, varies with variation in the phase angle between the voltages of the plants tied together. These curves represent the theoretical transmission of power, on the assumption that the line copper losses are part of the load carried from the plant busses and are divided between the plants in proportion to their bus voltages. This was done in order to show the real transfer of load that takes place between the two plants. These curves, and all other curves in this paper are calculated for three phase transmission, the values of power being the total power transmitted and the values of voltage the voltage between line wires of the circuit.

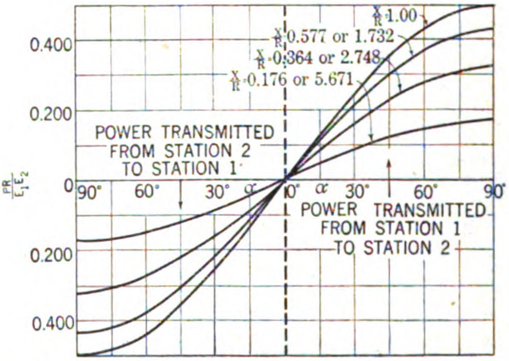


FIG. 2—POWER TRANSMISSION OVER TIE LINE

Resistance and voltages constant.

Line reactance and phase-angle between station voltages variable.

Three-phase circuit.

α = phase angle between E_1 and E_2.

β = $\tan^{-1} E/R$

$$\frac{PR}{E_1E_2} = \cos \beta \sin \beta \sin \alpha = \frac{XR}{Z^2} \sin \alpha.$$

The forces tending to pull paralleled plants out of phase are produced by the variations in the supply of power to the generators and by the variations in the loads drawn from their busses. For example, assuming that the steam governing devices are set so as to make the two plants share the total load equally at all times, one-half of any increase in the load on the bus of one station would have to be carried by the other. That this could be done, the station at whose bus the increase occurred would have to drop behind by a phase angle sufficiently large to permit of the necessary additional amount of power being transmitted over the tie line to meet the new condition. The higher the impedance of the tie line, the greater will be the phase angle required; and if the increase in load takes place suddenly, the lagging plant will at first drop too far behind because of its inertia, and will perform several "vibrations" before coming stable in its new position. In practise, therefore, the phase angle is constantly varying, the degree of variation depending on the magnitude and rapidity of the load fluctuations and on the impedance of the tie line. If it varies too rapidly or over too wide a range, an unstable or "pumping" condition will be created, which will cause swinging loads on the machines and bad voltage fluctuations, and may sufficiently increase the current in the tie line to open the line breakers and separate the plants. To obtain satisfactory parallel operation, therefore, the resistance and reactance of the tie line must be low enough to permit of a sufficiently free exchange of power between plants so that under the most severe conditions of load fluctuations the phase angle between stations will never vary sufficiently to cause harmfully unstable conditions or to open line breakers. In general, practical limitations of carrying capacity of the conductor and of line losses limit the maximum permissible phase angle to from 10 to 30 degrees.

The ability of any line to hold two plants together in satisfactory parallel operation may be called its "Synchronizing Power," which is defined as the change in the amount of power that the line will transmit for each degree change in phase displacement of the voltages of the stations it ties together. Mathematically, this means the rate of change in power transmitted with respect to change in phase angle, and is represented by the "slope" of the curves of Fig. 2. The formula is as follows:

$$Ps = \frac{E_1 E_2}{1000} \times \frac{X}{Z^2} \times \cos a.$$

where

E_1 = voltage at transmitting station.

E_2 = voltage at receiving station.

X = the reactance of the tie line.
Z = the impedance of the tie line.
a = the phase angle between E_1 and E_2.
Ps = synchronizing power in kilowatts.

To be rigidly accurate, the X and Z used above should include the armature windings and bus connections of the generators at the plants, but as these generally have very low impedance compared to the impedance of the line, they can ordinarily be neglected.

On a given line, the greatest change in the amount of power transmitted for a given change in phase angle between the station voltages occurs when the phase angle is zero, while the least change occurs when the angle is 90 degrees. (See Fig. 2). The synchronizing power of a given line is therefore a maximum when the phase angle is zero and zero when the phase angle is 90 degrees. Since the phase angle increases as the load transmitted increases, the synchronizing power decreases as the load transmitted increases.

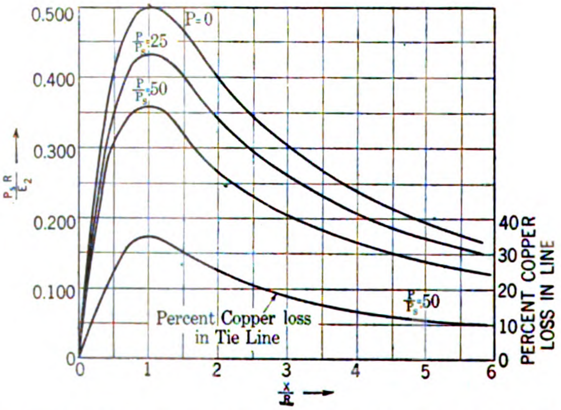


FIG. 3—SYNCHRONIZING POWER UNDER NORMAL OPERATING CONDITIONS

Power factor of load transmitted taken as unity.

$$P_S = E_1 E_2 X / Z^2 \cos \alpha$$

The curves of Fig. 3 show the synchronizing power of lines having the same resistance with varying reactances, when carrying loads of from 0 to one-half the synchronizing power of the line. It will be seen that for a line of given resistance the synchronizing power is greatest when the reactance-resistance ratio of the line is unity and decreases rapidly as this ratio changes from unity value.

While the synchronizing power of a line as defined above may be easily calculated, it is not so easy to determine the amount of synchronizing power that is necessary in a given case to secure satisfactory parallel operation. This will depend on many factors—among them the types of prime movers and their load-speed characteristics, and the character of the load delivered from the busses of the two plants. Reciprocating engine plants will require higher synchronizing power than turbine plants. Loads having rapid and large fluctuations will require more synchronizing power than steady loads. In checking up a number of actual cases, it has been found that under the conditions of fluctuating power load as found in the Pittsburgh district, the least line synchronizing power which will give satisfactory parallel operation of large turbine plants, with the relatively steady load of large systems, is a synchronizing power approximately equal to the capacity of the smaller plant to be paralleled, while with smaller plants, consisting partly of reciprocating engines and partly of turbines and the relatively high load fluctuations of the smaller systems, the tie line to give stable operation must have a synchronizing power equal to not less than 1.5 times the capacity of the smaller plant.

Inasmuch as the synchronizing power of a tie line depends upon a number of factors as explained above, it is obvious that any accurate criterion of the ability of a given line to hold two plants together must take account of all these factors. For example, it is sometimes said that a line having a capacity equal to a certain percentage of that of the smaller plant to be paralleled will give satisfactory operation. Yet two lines may be designed for just this capacity at the same voltage with widely different synchronizing powers. For similar reasons it cannot be assumed that a line which develops not more than a certain copper loss will be satisfactory, for such a statement does not take account of all of the variables.

Synchronizing power of the tie line becomes a limiting factor when the line voltage is low for the distance transmitted. When the value of volts per mile is relatively high, the synchronizing power will be found ample.

Synchronizing power must be given equal consideration whether there are generators or loaded synchronous motors at the receiving end of the line. It is unimportant in connection with synchronous condensers, however, since the energy which they take is always a very small percentage of the maximum power transmitted over the line.

The division of load between two plants in parallel depends of course upon the governor adjustments on the steam end of the prime movers; the division of wattless load associated with the energy load depends upon the voltages generated by the two plants and may be entirely different from the division of real load or energy supply. Thus the plant at one end of a line might supply all of the energy required while the plant at the other end might supply all of the wattless load.

By suitable voltage adjustments the plant which supplies power to the tie line may be made always to supply the wattless component associated with that power—under which condition the difference in voltage at the two busses will vary with the load on the line, being zero at no-load and a maximum when the maximum load is transmitted. Ordinarily, however, this operation produces too wide a range of voltage at the station busses to be satisfactory, and it becomes necessary to regulate the voltages within a closer range. This is possible, since the difference in voltage which is developed between the two ends of a transmission line when power is transmitted over it, depends not only on the amount of power transmitted but also on the amount of wattless energy. Given a certain voltage difference to be maintained between the ends of the line, there is a certain amount of load which with the wattless component associated with it, will just absorb that voltage difference. When the power transmitted is less than this value it becomes necessary in order to maintain the required voltage difference to set up a wattless cross current between the generators of the two stations, which current has the effect of lowering the power factor of the transmitting station and raising the power factor of the receiving station. When the power transmitted is more than the given value, the cross current must be in the opposite phase and has the opposite effect on the power factors of the two stations. The result is that the transmitting station has excess wattless current to take care of when the load on the tie line is light while the receiving station has excess wattless current to take care of when the load on the tie line is heavy. This is provided for by installing generators rated at a sufficiently low power factor or by installing synchronous condensers. At stations where the excessive cross current occurs only at periods of light load, more generators of normal power factor rating may be run at such periods than would be required by the energy load only—a method which is wasteful of coal, but may be more economical than the installation of additional equipment to take care of off-peak wattless current.

Fig. 4 shows how the wattless current in lines of different characteristics must be varied as the energy transmitted varies, in order to maintain constant bus voltages at both stations. Where the curves are below the horizontal zero line the wattless current in the tie line is lagging with respect to the voltage of the transmitting station and leading with respect to that of the receiving station. Where the curves are above the zero line, the wattless current is leading with respect to the voltage of the transmitting station and lagging with respect to the voltage of the receiving station.

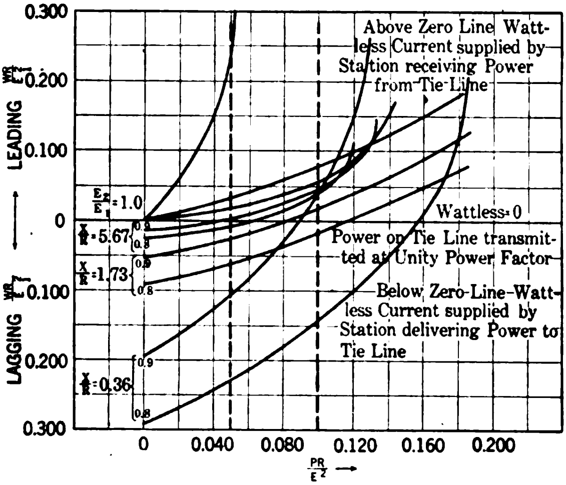


FIG. 4—WATTLESS CURRENT VS. POWER IN TIE LINE

The important points brought out by the curves of Fig. 4 are:

(1) The variation in wattless current for a given variation in load is very much greater where the reactance-resistance ratio of the line is low than where it is high. This means that the wattless cross current required to maintain constant bus voltages and the excess copper losses and wattless generating capacities arising therefrom increase very rapidly as the reactance-resistance ratio of the line decreases.

(2) When the same voltage is maintained on the busses of

both stations and load is transmitted over the tie line, the wattless cross current which is set up, always leads the voltage of the transmitting station and increases as the load transmitted increases. This means that the receiving station not only must supply all of the wattless current associated with the load received from the other station, but must also supply a certain amount of wattless cross current to the line in order to hold up the bus voltage.

(3) In order that the lagging wattless current associated with a given load as well as the load itself may be transmitted by the tie line, the voltage at the receiving station must be lower than that of the transmitting station.

(4) In view of the conditions shown by Fig. 4, it is necessary when laying out an installation in which constant voltages are to be maintained at the power station busses, to consider the conditions created when the minimum amount of power, as well as when the maximum amount is transmitted over the tie line.

In this connection it is interesting to note that the maximum amount of power which can be transmitted over a given line is independent of the reactance when sufficient wattless current can be generated at the end of the line, and depends only on the resistance of the line. It is that amount of power which equals the square of the transmitting voltage divided by four times the resistance. The voltage at the receiving end to give the maximum power is equal to the impedance divided by twice the resistance, hence is one-half of the transmitting voltage when there is no reactance, is equal to the transmitting voltage when the reactance is 1.732 times the resistance, and is greater than the transmitting voltage for a greater reactance. The very excessive line loss and wattless generating capacity required at the receiving end prohibit ever taking from a line the maximum amount of power that it can transmit.

When it becomes necessary to maintain the same bus voltages at both stations with very light loads transmitted as are maintained at full load, the wattless cross current may develop into an item of considerable cost. For this reason it becomes desirable to reduce it as much as possible. This can be done in two ways as follows:

a. By varying the voltage delivered to the tie line at the transmitting station as the load varies.

b. By varying the impedance of the tie line as the load varies.

The voltage delivered to the tie line is varied through the use of taps on the line transformers, or by means of an inductive regulator or synchronous booster. This method causes little variation in the synchronizing power of the tie lines, but involves considerable expense for special equipment.

The impedance of the tie line is varied through the use of reactance external to the lines or, when the tie circuit consists of several lines in parallel, by varying the number of lines in service. Both of these methods decrease the synchroniznig power as the impedance is increased, but involve little or no cost for special equipment, and will be found of very real value in many cases. It often happens that by a simple switching operation some of the short-circuit limiting reactances at the power stations can be switched into the lines used for paralleling, so that the impedance of these lines can be materially increased at light load periods. Changing the number of lines in service is of course accomplished by the use of the switches regularly installed with the lines, and so requires no special equipment at all.

The design of a line to transmit a given amount of power over a given distance involves a consideration of voltage, resistance, reactance, losses, and charging current of the line, and of wattless generating capacity in the form of synchronous condensers at the receiving end of the line. The selection of the proper voltage involves many factors outside of the scope of this paper, and will not be discussed. To obtain a minimum total cost of line at any given voltage, the annual cost of the copper losses in the line should equal the annual cost of the investment in copper; then, in order to obtain the minimum total cost of transmission, the proper size of synchronous condenser should be installed at the end of the minimum cost line to give the minimum total cost of line and condenser per kilowatt delivered at the end of the line. Thus the cost of copper and copper losses determine the resistance of the line, while the cost of synchronous condenser capacity in relation to the cost of the line determines how many kilowatts will be transmitted for each ampere of line current, by fixing the power factor of the load transmitted, and what is equally important, the voltage at the receiving end of the line. The charging current due to the capacitance of the line produces the effect of approximately the equivalent number of kilovolt-amperes in synchronous condenser capacity located at the middle point of the line and supplied with no additional investment.

When a line is to be designed for paralleling two plants, the minimum as well as the maximum amount of power to be transmitted, and the direction of transmission of each, must be determined from the characteristic curves of the loads supplied from the two busses, from the operating schedules desired of the prime movers at the respective stations, and to a lesser degree, from the load-speed characteristics of the machines and the fluctuating or steady nature of the load. The synchronizing power must also be given due consideration, and if constant bus voltages are to be maintained with a variable load transmitted between stations, the cost of the additional line loss and additional wattless generating capacity required because of the cross current, as well as the cost of the line and synchronous condenser capacity, must be considered in designing the line for minimum total cost of operation.

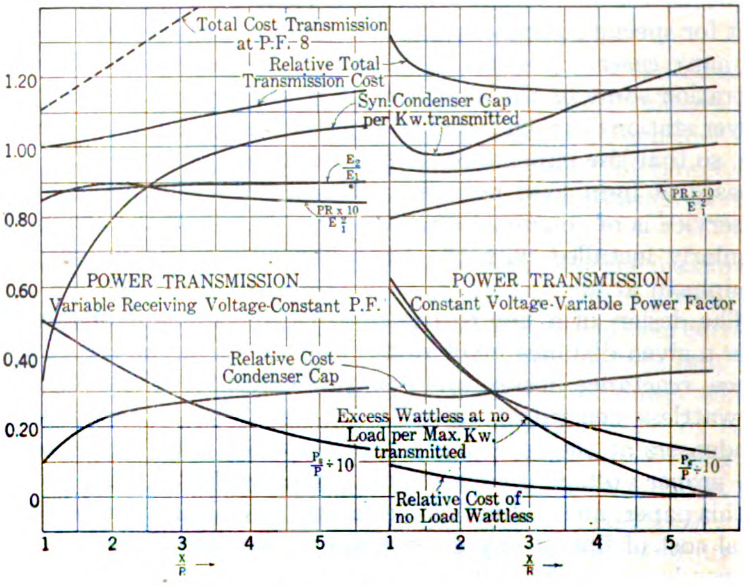


Fig. 5—Power Transmission Data

Transmission voltage 1000 volts per mile.

Cost of copper = Cost of copper loss.

Synchronous condenser capacity and receiving voltage to give minimum total transmission cost.

Power factor of load = 0.8.

Minimum load = 0.

In Fig. 5, curves have been calculated on the basis just outlined to determine the minimum total cost of transmission of a constant amount of power at a fixed voltage per mile, and the synchronizing power of the line resulting therefrom for various values for the ratio of reactance to resistance of the line. The following figures have been assumed as a basis:

Transmission voltage, 1000 volts per mile.

Cost of copper, 22 cents per pound.

Cost of synchronous condenser capacity, $5.00 per kv-a.

Losses of condenser, 3.5 kw. per kv-a. of capacity.

Annual cost of investment, 15 per cent.

Cost of energy, 2 mills per kilowatt-hour.

Power factor of load delivered from busses of both stations, 80 per cent.

Load factor, 50 per cent.

Range of load transmitted, 0 to maximum.

The reactance-resistance ratio of the line is determined chiefly by the frequency, size-of conductors, and design of the step-up and step-down transformers. The inherent reactance of transformers goes up rapidly with their voltage, because of the increased spacing required between their high- and low-tension windings, and low reactance at high voltages is attained only by an abnormal and costly design. The reactance of a given line at given frequency, therefore, can only be reduced by splitting it up into a number of parallel lines having smaller conductors and providing abnormally designed transformers, both of which methods are very costly. On the other hand, the reactance of a line can be readily increased to almost any desired value for a few per cent of the cost of the line by the installation of reactance coils. It is therefore fortunate that good voltage regulation can be attained with high reactances.

High voltage lines are generally designed for large blocks of power, making the combined reactance of the large conductors and of the transformers inherently high. Low voltage lines, with relatively small conductors, and often no transformers, have inherently low reactance.

On the left hand side of the curve sheet, Fig. 5, are shown the conditions where the bus voltage of the receiving station varies with the load. As the reactance-resistance ratio increases from 1 to 5.5, the total cost of transmission increases 16 per cent, showing that high reactance means a slight increase in total cost of transmission, under the minimum cost conditions. The synchronous condenser capacity goes up from 0.33 kv-a. per kilowatt transmitted, corresponding to

90 per cent power factor lagging in the line, to 1.06 kv-a. per kilowatt transmitted, corresponding to 95 per cent power factor leading in the line. Unity power factor obtains when the reactance-resistance ratio is 1.8. The cost of the condenser capacity varies from 9 per cent to 35 per cent of the cost of the line and line losses.

On the right hand side of Fig. 5 are shown conditions when the bus voltages are held constant as the load on the line is varied from zero to the maximum for which the line is designed. The wattless cross current necessary to maintain constant bus voltages introduces an additional element of cost, so that the total cost is higher than before for all values of the reactance-resistance ratio of the line. Furthermore, the total cost increases, instead of decreases, as this ratio decreases. This is because, with a given line resistance, the cross current required to maintain constant voltage increases rapidly as the reactance decreases, as is indicated by the curve showing the wattless cross current required with no power transmitted, which runs from zero for a reactance-resistance ratio of 5.7 up to 0.67 kv-a. per kilowatt of line capacity when the ratio is unity. The minimum attainable cost under these conditions is however very nearly reached when the reactance-resistance ratio is 2.5, so that the only advantage to be gained by a greater proportion of reactance is the raising of the voltage at the receiving end of the line, a feature which is only of importance when power is transmitted in both directions.

Under constant voltage conditions, more synchronous condenser capacity is used, with the result of raising the voltage at the receiving station and cutting out sufficient wattless cross current to more than pay for the additional condenser capacity. The cost of the condenser capacity runs from 30 per cent to 40 per cent of the cost of the line and line losses.

The ratio of synchronizing power to maximum load transmitted over the specified tie line varies from approximately 6, when the reactance-resistance ratio is 1, down to 1.3 when the ratio is 5.7—slightly higher than before because of the higher receiving voltages.

The curve giving values of $\frac{PR \times 10}{E_1^2}$ may be called the design curve. With the transmission voltage E_1 fixed, the resistance R of the line which will transmit a given amount of power

P at minimum cost, or the amount of power *P* which can be transmitted at minimum cost per kilowatt over a line having a given resistance *R* can be obtained immediately from this curve.

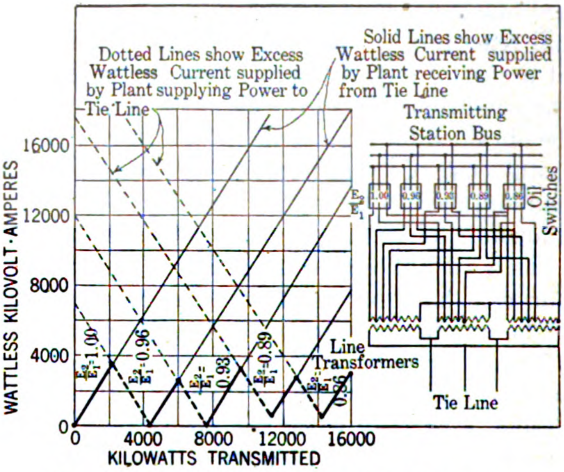
Comparing the curves under the condition of variable or constant bus voltage, it is found that for a reactance-resistance ratio in the line of 5.7, the constant bus voltages are obtained at practically no additional cost. As the ratio decreases, however, the cost of securing constant bus voltages increases, being 8 per cent of the total transmission cost for a ratio of 3, and 31 per cent for a ratio of 1. If the inherent reactance of a specified line is not high enough to give economical operation additional reactance in the form of reactance coils can be inserted at a cost of only a few per cent of the cost of the line. Under the conditions assumed, therefore, constant bus voltages should be obtained for an increase of not more than 10 per cent of the total cost of transmission—which is a very low cost for the advantages to be gained thereby.

The transmission voltage in relation to the distance of transmission has a very direct bearing on the line design problem. In the curves it has been assumed to be 1000 volts per mile of line. If the number of volts per mile is lower, more synchronous condenser capacity will be used and the synchronizing power will be decreased and may become the limiting factor of the design, especially when the power to be transmitted is a small part of the station capacity. In this case, it becomes necessary to use more copper than is required for the load, or to reduce the reactance, or to do both, in order to obtain sufficient synchronizing power.

If the number of volts per mile is greater than 1000, less synchronous condenser capacity will be used and more synchronizing power will be obtained than is indicated in Fig. 5.

In general, it will be found that where constant bus voltages are necessary, the best tie line will be the one which has the greatest reactance consistent with the necessary synchronizing power. Transmission with high reactance, however, necessitates an ample amount of wattless generating capacity at the receiving station, in order to hold up the voltage. Where this is not available, so that a considerable amount of wattless current must be supplied with the load from the transmitting station, high line reactance is impracticable and the cost of maintaining constant bus voltages is greatly increased.

In Figs. 6 and 7 are shown data worked out for specific cases, to determine how the wattless cross current could be reduced. In both cases it was necessary to maintain constant bus voltages at the two plants to be paralleled. In Fig. 6, loads varying from 0 to 15,000 kw. were to be transmitted from one station to the other. In order to keep the excess wattless current—by which is meant the wattless current which either station would be called upon to supply in addition to that associated with the real load it was delivering—below the limit of 4000 kv-a., it was necessary to provide four additional taps on the line transformers and four additional oil switches at the transmitting station to give the voltages as shown. Fig. 7 shows how in a given case, where two lines tie the two plants together, the wattless cross current was reduced at light load periods by switching in a bus limiting reactance already installed, which happened to be just large enough to double the reactance-resistance ratio of the line. Fig. 7 also shows the effect of cutting out one of the two tie lines.



Fif. 6—Effect of Varying Bus Voltages

Transmission on four No. 0 lines in parallel.
Resistance = 0.52 ohn. $X/R = 1.33$
Power factor of load 0.8. Voltage $E_1 = 11,000$.
Synchronizing power = 2.25 times the capacity of plant to be tied in.

Fig. 8 is a chart which was worked out to guide the system operators in regulating the cross current between the stations connected by two lines. If two lines are in service and the power factor drops below 45 per cent, one line is immediately cut out. This doubles the kilowatts transmitted by the remaining line, but does not increase its current, so that by cutting out the other line approximately 180 amperes of cross current are eliminated.

In concluding with a brief summary, it must be borne in mind that in designing a tie line to meet any specified condition many variables enter the problem. In general, costs of copper, steel, and coal go up and down together, so that absolute costs are not so important as relative costs of these items. The load factor of the power transmitted affects the overall costs of line losses, and therefore the amount of the copper used. The transmission voltage in relation to the transmission distance has a very direct bearing on the amount of synchronous condenser capacity to be used, and on the synchronizing power of the line. Since the data and curves which have been shown are based upon a series of specific assumptions, which while sufficiently correct under the conditions at hand, might have to be materially changed to meet other conditions, the data presented are of interest in showing the relative weight of the different factors rather than in determining absolute values. It is hoped that in showing the effect of the different variables on the problem as a whole, a guide may be furnished to the

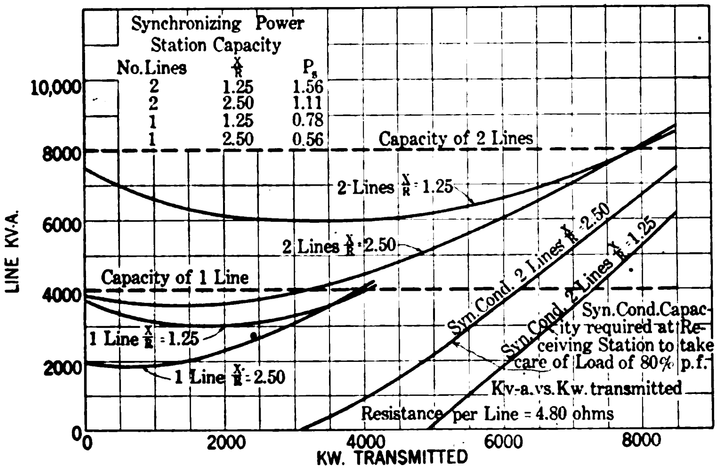


FIG. 7—REGULATION OF WATTLESS CROSS CURRENT BY VARYING THE REACTANCE AND NUMBER OF TIE LINES IN SERVICE

lines which should be followed in working out any specific case. With these limitations in mind, the following points may be emphasized:

In order to operate two power plants satisfactorily in parallel the transmission line which ties them together must have sufficient "synchronizing power," as well as sufficient carrying capacity to carry the maximum load to be transmitted between them. The synchronizing power of a given line depends upon its resistance and reactance, upon the bus voltages maintained at its ends, and upon the maximum kilovolt amperes it must transmit. The ability of different lines to provide satisfactory parallel operation cannot be measured by any standard which does not take account of all of these factors. It has been found from the writer's experience that a synchronizing power about equal to the kilowatt capacity of the smaller plant to be paralleled, for large turbine plants with load fluctuations of relatively small percentage of their capacity, and of 1.5 times the smaller plant capacity for mixed engine and turbine plants with relatively large load fluctuations, is about the least that a line can have to give satisfactory parallel operation.

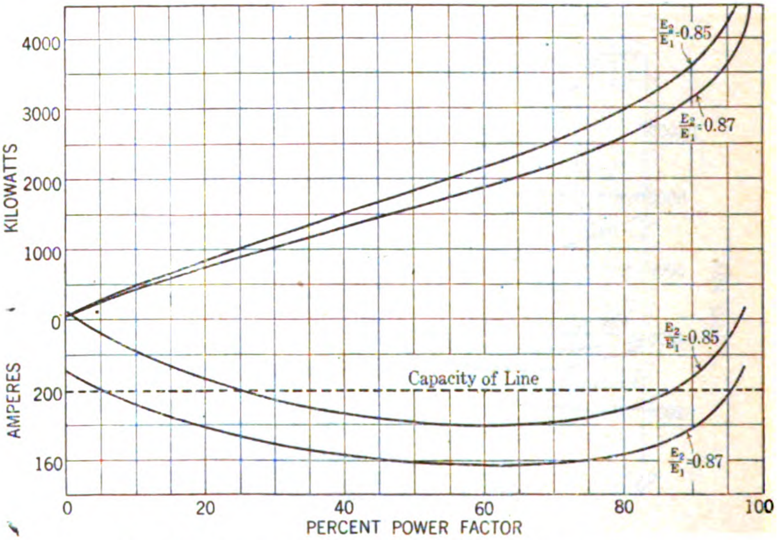


Fig. 8—System Operator's Working Diagram

Performance of one tie line.

R = 4.8 ohms. X = 6.0 ohms.

When the voltage per mile of transmission is high, line capacity, as determined by load and operating conditions at the two stations, is the limiting factor; when the voltage per mile is low, synchronizing power more often marks the limit, especially when the reactance is high and the load to be transmitted relatively small. The necessity for sufficient line synchronizing power applies equally whether generators or loaded synchronous motors are at the end of the line, but is unimportant in connection with synchronous condensers at the end of the line.

The design of equipment for transmitting a block of power over a given distance at minimum cost must take into account the use of synchronous condenser capacity at the receiving end of the line. The condenser is effective in raising the receiving voltage as well as in controlling the transmission power factor, and materially reduces the amount of copper required in the line. The amount of condenser capacity which may be economically used depends on the power factor of the load, the relation between the cost of line capacity and condenser capacity, and the reactance-resistance ratio of the line. Where this ratio is high, sufficient condenser capacity may be justified to produce a considerable leading component in the tie line current. In a line of given resistance, with the receiving voltage unregulated, the total cost of transmission increases slightly with the increase in reactance.

Where synchronous machines of sufficient capacity, either condensers or generators, are installed at both ends of the line, the bus voltage of both stations can be maintained constant as the load transmitted over the line varies, by the creation of a wattless cross current. This wattless current, however, involves an additional cost in copper loss and in the wattless generating capacity required at one or both stations to take care of it, which cost is small when the reactance-resistance ratio of the line is sufficiently high, but which rapidly increases as the reactance decreases, and for low line reactance becomes very important. This wattless current can be materially reduced under certain conditions, by varying the voltages at the ends of the line as the load varies through the use of transformer taps, by inserting additional reactance in the line at light loads, or, when the stations are tied together by several parallel lines, by cutting out one or more lines as the load decreases.

The increase in the cost of transmission with constant bus voltages caused by this wattless cross current represents the cost of eliminating the regulation of the tie line. The wattless cross current decreases as the reactance-resistance ratio of the line increases, but the synchronizing power also decreases. Hence will generally be found that the best design of transmission equipment for constant bus voltages is that which makes the reactance of the line as high as is permissible for the synchronizing power required. With such a design, the cost of maintaining constant bus voltages—that is, of eliminating the regulation of the tie line—does not amount to more than a few per cent of the total cost of transmission, which is a very small price to pay for the operating advantages gained. It must be remembered, however, that to obtain constant bus voltages at this slight cost, the installation of sufficient wattless generating capacity at the receiving station is absolutely essential—a feature, unfortunately, that is too often lacking in existing systems.

APPENDIX

In what follows, the formulas are developed which were used in calculating the data presented in the foregoing paper.

Referring to Fig. 9,

Let E or E_1 = Voltage at transmitting station.

E_2 or kE = Voltage at receiving station.

E_0 = Voltage across tie circuit.

$k = E_2/E$

α = Angle between E and E_2

z = Impedance of tie circuit

r = Resistance of tie circuit

x = Reactance of tie circuit

$\beta = \tan^{-1} x/r$

P_1 = Power delivered to tie circuit by transmitting station in watts.

W_1 = Wattless delivered to tie circuit by transmitting station in volt-amperes

VA_1 = Total volt amperes delivered to tie circuit by transmitting station

P_2 = Power received from tie circuit by receiving station, in watts

W_2 = Wattless received from tie circuit by receiving station in volt-amperes

VA_2 = Total volt-amperes received from tie circuit by receiving station

P_s = Synchronizing power of tie circuit, in watts
I_0 = Current in tie circuit, in amperes
θ_1, θ_2 = Angles between voltages as shown in Fig. 9.

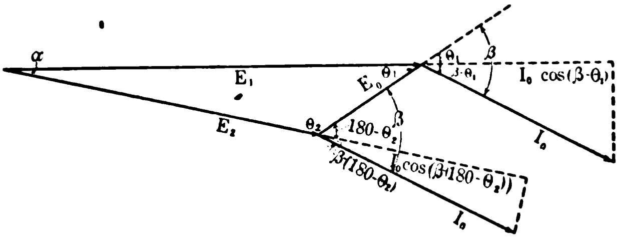


FIG. 9—VOLTAGE AND CURRENT RELATIONS WHEN POWER IS TRANSMITTED OVER TIE LINE

From the triangle of voltages,

$$\frac{E_1 + E_2}{E_1 - E_2} = \frac{\tan \frac{1}{2}(\theta_2 + \theta_1)}{\tan \frac{1}{2}(\theta_2 - \theta_1)} = \frac{1 + k}{1 - k} \tag{1}$$

$$\tfrac{1}{2}(\theta_2 - \theta_1) = \tan^{-1}\left(\frac{1 - k}{1 + k} \operatorname{cotan} \frac{\alpha}{2}\right) \tag{2}$$

$$\tfrac{1}{2}(\theta_2 + \theta_1) = \tfrac{1}{2}(180 - \alpha) = 90 - \alpha/2 \tag{3}$$

Adding (2) and (3)

$$\theta_2 = 90 - \alpha/2 + \tan^{-1} \frac{1 - k}{1 + k} \operatorname{cotan} \alpha/2 \tag{4}$$

whence

$$\tan(90 - \theta_2) = \frac{\tan \alpha/2 - \dfrac{1 - k}{1 + k} \operatorname{cotan} \alpha/2}{1 + \dfrac{1 - k}{1 + k} \tan \alpha/2 \operatorname{cotan} \alpha/2}$$

$$= \frac{k - \cos \alpha}{\sin \alpha} \tag{5}$$

Therefore

$$\operatorname{cotan}(180 - \theta_2) = -\tan(90 - \theta_2) = \frac{\cos \alpha - k}{\sin \alpha} \tag{6}$$

Subtracting (2) from (3)

$$\theta_1 = 90 - \frac{\alpha}{2} - \tan^{-1}\left(\frac{1 - k}{1 + k} \operatorname{cotan} \frac{\alpha}{2}\right) \tag{7}$$

whence

$$\tan(90 - \theta_1) = \frac{\tan\frac{\alpha}{2} + \frac{1-k}{1+k}\cot\frac{\alpha}{2}}{1 - \frac{1-k}{1+k}\tan\frac{\alpha}{2}\cot\frac{\alpha}{2}}$$

$$= \frac{1 - k\cos\alpha}{k\sin\alpha} \qquad (8)$$

Therefore

$$\cot\theta_1 = \frac{1 - k\cos\alpha}{k\sin\alpha} \qquad (9)$$

Again from the voltage triangle,

$$\frac{E_0}{E_2} = \frac{E_0}{k\,E} = \frac{\sin\alpha}{\sin\theta_1} \qquad (10)$$

whence

$$E_0 = \frac{k\,E\sin\alpha}{\sin\theta_1} \qquad (11)$$

and $$I_0 = \frac{k\,E}{z} \cdot \frac{\sin\alpha}{\sin\theta_1} = k\,E \cdot \frac{\cos\beta}{r} \cdot \frac{\sin\alpha}{\sin\theta_1} \qquad (12)$$

Now

$$P_1 = E \,.\, I_0 \,.\, \cos(\beta - \theta_1) \qquad (13)$$

$$= E^2 \cdot \frac{k\cos\beta}{r} \cdot \frac{\sin\alpha}{\sin\theta_1} \cdot \cos(\beta - \theta_1) \qquad (14)$$

$$= E^2 \cdot \frac{k\cos\beta}{r} \cdot \frac{\sin\alpha}{\sin\theta_1} \cdot (\cos\beta\cos\theta_1 + \sin\beta\sin\theta_1) \qquad (15)$$

$$= E^2 \cdot \frac{k\cos\beta}{r} (\cos\beta\sin\alpha\cot\theta_1 + \sin\alpha\sin\beta) \qquad (16)$$

By substituting value of cotan θ_1 from (9)

$$P_1 = E^2/r\,k\cos\beta \left(\sin\alpha\sin\beta + \sin\alpha\cos\beta\left\{\frac{1 - k\cos\alpha}{k\sin\alpha}\right\}\right) \qquad (17)$$

$$= E^2/r\,k\cos\beta \left(\sin\alpha\sin\beta + \frac{\cos\beta}{k} - \cos\alpha\cos\beta\right) \qquad (18)$$

$$= E^2/r\,k\cos^2\beta\,(\sin\alpha\tan\beta + 1/k - \cos\alpha) \qquad (19)$$

Again, $W_1 = E \, . \, I_0 \, . \sin(\beta - \theta_1)$ **(20)**

$$= E^2 \, . \, \frac{k \cos \beta}{r} \, . \, \frac{\sin \alpha}{\sin \theta_1}$$

$$(\sin \beta \cos \theta_1 - \cos \beta \sin \theta_1) \qquad \mathbf{(21)}$$

$$= E^2 \, . \, \frac{k \cos \beta}{r}$$

$$(\sin \alpha \sin \beta \operatorname{cotan} \theta_1 - \sin \alpha \cos \beta) \qquad \mathbf{(22)}$$

Substituting value of cotan θ_1 from (**9**)

$$W_1 = E^2/r \, k \cos \beta$$

$$\left(\sin \alpha \sin \beta \left\{ \frac{1 - k \cos \alpha}{k \sin \alpha} \right\} - \sin \alpha \cos \beta \right) \qquad \mathbf{(23)}$$

$$= - E^2/r \, k \sin \beta \cos \beta$$

$$\left(\frac{\sin \alpha}{\tan \beta} + \cos \alpha - \frac{1}{k} \right) \qquad \mathbf{(24)}$$

$$= - E^2/r \, k \cos^2 \beta \tan \beta$$

$$\left(\frac{\sin \alpha}{\tan \beta} + \cos \alpha - \frac{1}{k} \right) \qquad \mathbf{(25)}$$

$$V A_1 = E \, . \, I_0 = E \, . \, k \, E \, . \, \frac{\cos \beta}{r} \, . \, \frac{\sin \alpha}{\sin \theta_1} \qquad \mathbf{(26)}$$

$$= \frac{E^2}{r} \, k \cos \beta \, \frac{\sin \alpha}{(1 + \operatorname{cotan}^2 \alpha)^{1/2}} \qquad \mathbf{(27)}$$

$$= \frac{E^2}{r} \, k \cos \beta \, . \sin \alpha \, . \, \frac{(k^2 + 1 - 2 \, k \cos \alpha)^{1/2}}{k \sin \alpha} \qquad \mathbf{(28)}$$

$$V A_1 = E^2/r \cos \beta \, (1 + k^2 - 2 \, k \cos \alpha)^{1/2} \qquad \mathbf{(29)}$$

Similarly,

$$P_2 = E_2 \, I_2 \cos (\beta - \{180 - \theta_2\}) \qquad \mathbf{(30)}$$

$$W_2 = E_2 \, I_2 \sin (\beta - \{180 - \theta_2\}) \qquad \mathbf{(31)}$$

$$V A_2 = E_2 \, . \, I_0 = k \, E \, . \, k \, E \, . \, \frac{\cos \beta}{r} \, . \, \frac{\sin \alpha}{\sin (180 - \theta_2)} \qquad \mathbf{(32)}$$

From which are obtained by substituting for cotan $(180 - \theta_2)$ its equal $\frac{\cos \alpha - k}{\sin \alpha}$ as obtained in (**6**).

$$P_2 \quad = E^2/r\, k \cos^2 \beta \,(\sin \alpha \tan \beta + \cos \alpha - k) \qquad (33)$$

$$W_2 \quad = \frac{E^2}{r}\, k \cos^2 \beta \left(\frac{\sin \alpha}{\tan \beta} + k - \cos \alpha\right) \qquad (34)$$

$$V A_2 = E^2/r\, k \cos \beta \,(1 + k^2 - 2\, k \cos \alpha)^{\frac{1}{2}} \qquad (35)$$

Copper Loss in tie Circuit. It is obvious that the copper losses in the tie circuit are equal to the power delivered to one end of the tie circuit minus the power received at the other end. That is, **(36)**

$$\begin{aligned} I_0^2\, r = P_1 - P_2 = {} & E^2/r\, k \cos^2 \beta \,(\sin \alpha \tan \beta + 1/k - \cos \alpha) \\ & - E^2/r\, k \cos^2 \beta \,(\sin \alpha \tan \beta + \cos \alpha - k) \end{aligned}$$

$$= E^2/r\, k \cos^2 \beta \,(k + 1/k - 2 \cos \alpha) \qquad (37)$$

Synchronizing Power. It may be assumed that the elements of line loss in P_1 and P_2 are variable loads supplied from the busses of transmitting and receiving stations, respectively. On this basis, the power actually transferred from one station to the other for a given phase angle α between their voltages as obtained from (**19**) to (**33**) is found to be

$$E^2/r\, k \cos^2 \beta \sin \alpha \tan \beta \qquad (38)$$

$$\text{or } E^2/r\, k \sin \beta \cos \beta \sin \alpha \qquad (39)$$

The synchronizing power P_s, is defined as the change in the amount of power transferred over the tie circuit for one degree change in phase between bus voltages.

Therefore

$$P_s = \frac{d}{d\, \alpha}\,(E^2/r\, k \sin \beta \cos \beta \sin \alpha) \qquad (40)$$

$$= E^2/r\, k \sin \beta \cos \beta \cos \alpha) \qquad (41)$$

which is equivalent to

$$\frac{E_1 E_2}{r} \,.\, \frac{x}{z} \,.\, \frac{r}{z} \,.\, \cos \alpha \qquad (42)$$

$$\text{or } E_1 E_2 \,.\, x/z^2 \,.\, \cos \alpha \qquad (43)$$

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PREDETERMINATION OF SYNCHRONOUS PHASE-MODIFIER PERFORMANCE

BY HUBERT V. CARPENTER

ABSTRACT OF PAPER

The author reviews the method for showing the behavior of transmission lines first given by Perrine and Baum and then shows how it can be used in determining the effect of the use of a synchronous motor operating without load for improving the power factor. The effect of the losses in the motor are shown both in their effect on the line alone and on the line with the step-up and step-down transfomrers included.

The diagram given shows both the improvement in voltage regulation and the change in power factor due to the phase-modifier for any assumed condition of loading for the transmission line.

The errors of the method are discussed with methods for determining their magnitude, and the advantages of the graphical treatment pointed out.

RAPIDLY growing demands upon our transmission systems for more power and better service have made it imperative in many cases that increased capacity be provided without delay. Increasing the capacity means in most cases improved regulation, but frequently demands also a better efficiency of operation in order that the maximum possible fraction of the output of the generators may be delivered. This is usually thought to demand higher voltages or heavier lines or duplication of lines, all of which require time as well as money.

It is not perhaps fully appreciated that a synchronous motor operating upon the system may, if properly proportioned, improve the efficiency as well as the regulation, thus accomplishing both of the things desired.

While the theory of the synchronous phase—modifier has been fully treated before the Institute it is hoped in the following to make its general effect upon a transmission system a little more easily grasped.

In the consideration of transmission problems the writer feels that far too little use has been made of the remarkable diagram first proposed by Perrine and Baum, (TRANS. A. I. E. E. May 1900.)

The peculiarities of this treatment are that the voltage at the receiver is assumed constant and that at the generator solved for, and that the current is treated throughout as made up of three independent parts, charging current, I_c; load current, $I \cos \phi$; and reactive or wattless component delivered, $I \sin \phi$. The electromotive force required to force each of these components of current through the line is then figured, first for the resistance and then for the reactance of the line, thus giving the following components of e. m. f. required; $\frac{R\,I_c}{2}$; $\frac{X I_c}{2}$; $R\,I \cos \phi$; $X\,I \cos \phi$; $R\,I \sin \phi$; and $X\,I \sin \phi$. The charging current values are divided by 2 because I_c distributes itself over the line in a way assumed here to be uniform.

To make up the regulation diagram, Fig. 1, the e. m. f. at the receiver, E, is assumed as the vector of reference and the above values added to get the total voltage needed at the generator.

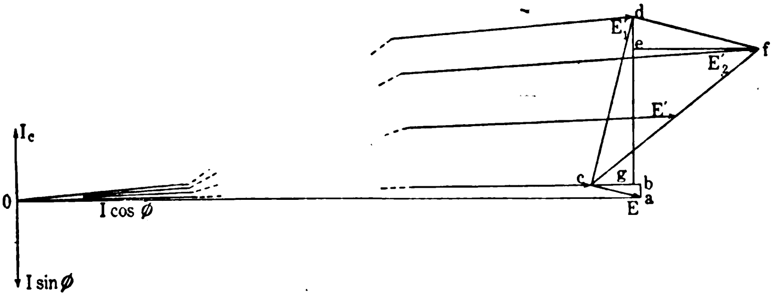

Fig. 1

In Figs. 1 and 2 $a\,b$ is $\frac{R\,I_c}{2}$, $b\,c$ is $\frac{X\,I_c}{2}$, $c\,g$ is $R\,I \cos \phi$, $g\,d$ is $X\,I \cos \phi$, $d\,e$ is $R\,I \sin \phi$ and $e\,f$ is $X\,I \sin \phi$, the last two being shown for 0.8 power factor, lagging. $\frac{R\,I_c}{2}$ and $\frac{X\,I_c}{2}$ are plotted first since they are closely constant and assumed to be exactly so here.

The total volts required to force the working component of current through the line is $c\,d$, and is equal to $Z\,I \cos \phi$. The value of $c\,d$ will therefore vary directly with the kilowatts delivered since E is assumed to be held constant. A scale of kilowatts may be therefore used along $c\,d$ as in Figs. 2 and 3.

An ampere scale may also be added if desired. In the same way a scale of reactive kv-a. may be laid off along *d f* as shown.

The advantage of the method lies in the fact that the entire performance of a line for all conditions of load is shown by one solution, and further that the effect of any change of load is shown directly for any assumed case. The thing really most desired in studying a design for a line is to learn the effect which will be produced by the greatest sudden change in load that may be expected. Questions of this sort are answered directly by this diagram.

Fig. 2 shows that the diagram as there made up is really a chart in which distances along the axis, *c d*, represent power in kilowatts, while distances along the axis, *d h*, represent reactive kv-a. Thus, the point, *d*, Fig. 2, represents 16,000 kw. at unity power factor, and, from the scale below requires 100.8 per cent of the receiver voltage at the sending end. Also point, *j*, shows that an addition of 6000 reactive kv-a., requires the generator voltage to be increased to 106 per cent of *E*. Further, a load of 12,000 kw. at 0.8 power factor, lagging, can be handled without drop in the line if a pure condensance requiring 8250 kv-a. be connected to the system. See points *k* and *k'*.

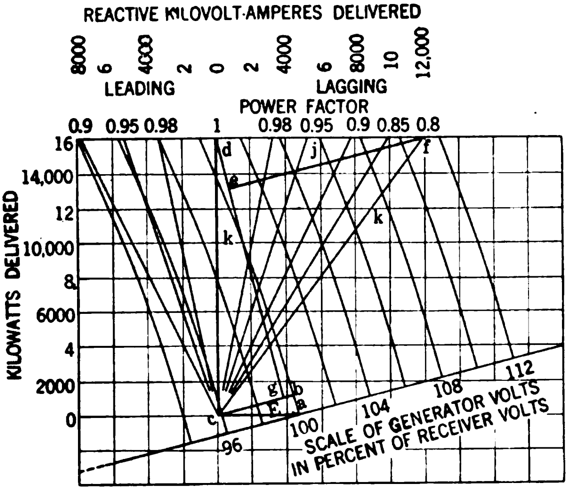

Fig. 2

The time thus spent in rehearsing the workings of the Perrine-Baum diagram is considered well spent for we are now ready to apply it directly to the problem of this paper.

In order to get reasonable accuracy in calculating the effect of an over-excited synchronous motor running on the line without load it is necessary to include the power losses in the machine itself.

To do this in a way best adapted to use with the regulation diagram just shown, the performance of the machine can be plotted in the form shown in Fig. 4. This represents the same current values as determined in the test for the "*V*" curves for the machine except that they are plotted according to their respective power factors and a scale of kw. one way and kv-a. the other used. In other words this plotting shows the active and the reactive components of the kv-a. taken by the machine for any total value, either over or under excited. The slight difference between leading and lagging losses shows the effect of the varying loss in the field windings for different excitations.

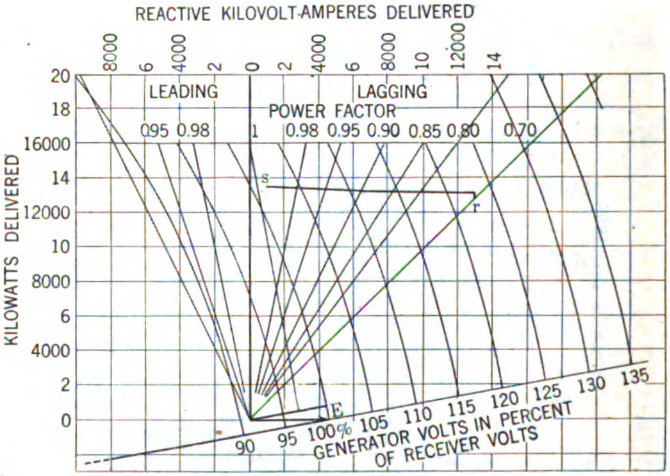

Fig. 3

It will be noted that the data for the machine is now plotted in the same form as is used in the Perrine-Baum chart, that is, with kw. for one axis and reactive kv-a. for the other, so that it can be drawn in directly to proper scale on the chart. This is done in Fig. 3. This figure shows, for example (see points *s* and *r*) that the addition of the phase-modifier working at full capacity of 12,000 kv-a. changes the load from 12,780 kw. at 0.7 power factor lagging, to 13,500 kw. at 0.99+ power factor lagging, and the line drop from 23 per cent to 2 per cent. It is evident that a condenser of one half this size would bring the line drop down to about 12 per cent and the power factor up to 0.88.

A study of the diagram shown and of the properties of the different sizes of line conductors will bring out the fact that a transmission line made up of very large conductors will respond more directly to the corrective action of a synchronous phase-modifier than one using small conductors. That is, if we substitute a conductor of one-half the cross-section of that used in the line figured above the resistance will be doubled but the reactance will be only about 6 per cent greater. This means that with the smaller wire the line, *c d,* of Fig. 2 will be much more inclined toward the horizontal and *d h* toward the vertical. This further tilting of the axes of the diagram makes the effect of a synchronous motor much less, so far as its usefulness in correcting regulation is concerned. It will still be effective in reducing the power lost in the line simply by its effect in reducing the value of the total current flowing in the line. This also applies to cases where the power line is made up of underground cable where the reactance is usually less than the resistance.

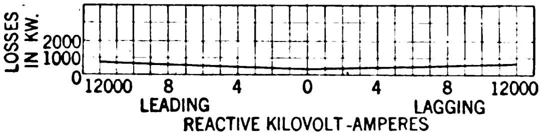

FIG. 4

Owners of small overhead lines may expect the same disappointing results in varying degrees depending on the material of the line, the size, and the spacing.

In all high-voltage systems where the use of phase-modifiers is most advantageous it is necessary to associate step-up and step-down transformers with the line whenever operated, and usually the transformer sets used with any line are the same from day to day. In all such cases there is no need of figuring the line behavior as a separate matter from that of the transformers which are really a part of the line. The resistance of a transformer, if taken over the ordinary range of working temperatures is only slightly variable, and its reactance, depending as it does on the relative positions of the windings and the dimensions of the non-ferrous portions of the leakage paths, is also quite constant and independent of changing load conditions. If then the same transformers are usually used with the line under consideration there is no reason why their resistance and reactance should not be included with the resistance and reactance of the line. Values for the low-tension coils must be changed to high-tension equivalents before adding them in.

In Fig. 3 is given the behavior of the same line as shown in Figs. 1 and 2 with the transformers included. The difference shows the futility of making an exact solution for the performance of a line alone which can never be used without its transformers. It also shows the faulty economy in trying to get a very good regulation in the line when the transformers will prevent it anyway.

Figs. 2 and 3 give the performance of a three-phase line 140 miles long with 300,000-cir. mil. stranded conductors spaced 12 ft., operating at 60 cycles and 110,000 volts between wires.

Fig. 3 includes the transformers which are assumed to handle 16,000 kv-a. at 0.8 power factor and to have a regulation of 1 per cent at unity power factor and 6 per cent at 0.8 power factor lagging.

It will be noted that under most conditions the ratio of X to R will be higher for the transformers than for the line. This may mean that a phase modifier will give good service in improving regulation where a study of the line alone would not make this apparent.

It seems that the reason more use has not been made of this method of studying transmission problems is based on the fact that it is considered inaccurate. The inaccuracy lies in the fact that the static charge which makes up the charging current is assumed to be uniformly distributed along the line, disregarding the variation in voltage, and also in the fact that the charging current is assumed for convenience to be just 90 degrees ahead of the receiver voltage. Inaccuracy is much more feared when the extent of the error is unknown. This difficulty is removed by the exact analytical methods available when needed, any of which may be applied to any one particular condition out of the variety which the chart represents and thus show the error for that point, in fact this is the way to learn to appreciate the graphical method which answers all questions with one solution. As a matter of fact it can be easily shown that the terms calculated in making up the Perrine-Baum diagram are, neglecting line leakage, nothing more or less than the first three terms of the following series which represents the behavior of a line to any required degree of exactness.

$$E' = E + I\,Z + \frac{Y\,Z\,E}{2} + \frac{Y\,Z^2\,I}{6} + \frac{Y^2\,Z^2\,E}{24} + \text{etc.}$$

For any of the lines now in use the error of the method outlined will be found to be well within all useful limits.

Presented at the Thirty-fifth Annual Convention of the American Institute of Electrical Engineers, Lake Placid Club, N. Y., June 24, 1919.

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GROUNDED NEUTRAL TRANSMISSION LINE

BY W. E. RICHARDS

ABSTRACT OF PAPER

The paper describes the conditions on the system in Toledo which was originally delta-connected. Serious trouble was experienced when a short circuit occurred especially with synchronous apparatus connected to the line which invariably failed due to the voltage drop occasioned by the severe short circuits on the delta system. This trouble was overcome by changing the transmission to a Y system with the neutral grounded. The effect of a short circuit with the new connection has been decidedly minimized.

THE subject will be treated with especial reference to the operation of a grounded-neutral transmission line having several elements not always desirable in handling high-tension voltage within city limits, namely, extremely high and long-span construction connected directly with an extensive underground transmission with its various connections to conversion apparatus.

The system in Toledo was built more on the line of developments following existing industrial requirements than a prearranged system where future requirements were anticipated.

In this case, an industry, by reason of circumstances, was located some four miles from the generating station. Conditions were such that it was not desirable for the customer to generate his own supply. His requirements started with a demand of from two to four thousand kilowatts, with the ultimate expected demand of eight or ten thousand. As the industry has exceeded their expected increase, the demand on this system will shortly run to sixteen thousand kilowatts, and possibly greater.

Geographical conditions and city ordinances determined that this transmission should be in part purely underground. There was fortunately located on the route selected, several substations which were badly in need of additional energy and such other developments that the company had in mind, that it was decided to install a 23,000-volt 25-cycle system, it being felt that this was the limit of successful high voltage underground operation. Certain features presented themselves at this time which made it desirable to have the transformers delta connected. This feature was thoroughly discussed and at that time no serious objections presented themselves and it was put into operation the early part of the year of 1915.

Some trouble developed due to weak spots in cable and joints but these faults were surprisingly low, considering the quantity of cables that were put into service at this time.

The system rapidly settled down to a successful continued operation and no faults developed that did not have a reasonable explanation, such as fault in material and joints, and joints not properly made.

Since correcting this condition the system has operated successfully with reference to the general plan, but a serious condition arose when a short circuit occurred, particularly disastrous to synchronous apparatus connected with the system, which would invariably fail by reason of the voltage drop occasioned by the severity of a short circuit on the delta system. The cables suffered severely, and in fact, in some cases the covers of the manholes blew off, taking on more the nature of an explosion if the short circuit occurred in the manhole.

It was then decided to change this transmission to a Y system with the grounded neutral. The transformers being constructed for delta operation, it was necessary to take the core out of the case, cut the coils apart and parallel them for 23,000 volts Y. A five ohm-resistance was inserted, which afterwards was removed, thereby operating the neutral directly to ground. The results of a cable failure now has a decidedly different effect.

In some cases no superficial evidence is present at the point of failure, and when such evidence is present, it is not of a severe nature to destroy adjacent cables and in no way presents the disastrous appearance as when trouble would occur with a system operating delta.

It is true that by experience a better understanding of protective apparatus resulted in changes to such apparatus which were beneficial, but it was felt that the successful operation of this system was largely due to the change from delta to Y grounded.

Referring to the Figs. 1, 2 and 3, the system is graphically shown, and presents some unique features as before mentioned.

Fig. 1 is the general scheme of the transmission, carrying

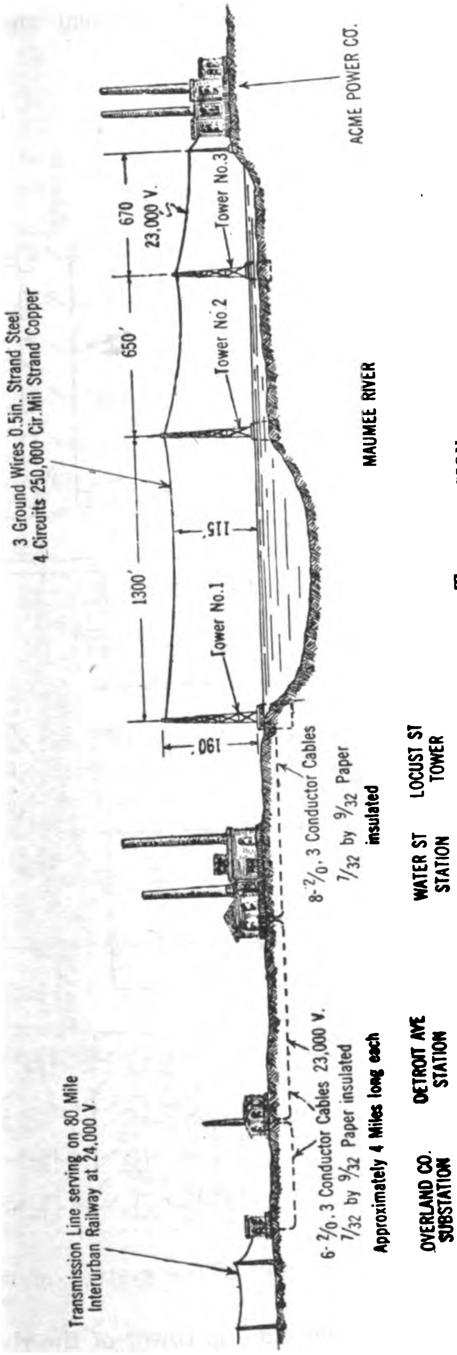
Transmission Line serving on 80 Mile Interurban Railway at 24,000 V.
6-2/0. 3 Conductor Cables 23,000 V. 7/32 by 9/32 Paper insulated
Approximately 4 Miles long each
OVERLAND CO. SUBSTATION
DETROIT AVE STATION
WATER ST STATION
8-2/0. 3 Conductor Cables 7/32 by 9/32 Paper insulated
LOCUST ST TOWER
190'
Tower No.1
1300'
115'
3 Ground Wires 0.5in. Strand Steel
4 Circuits 250,000 Cir.Mil Strand Copper
MAUMEE RIVER
Tower No 2
650'
Tower No.3
670
23,000 V.
ACME POWER CO.

Fig. 1—General Scheme of Transmission

such information as will give the physical characteristics of the system.

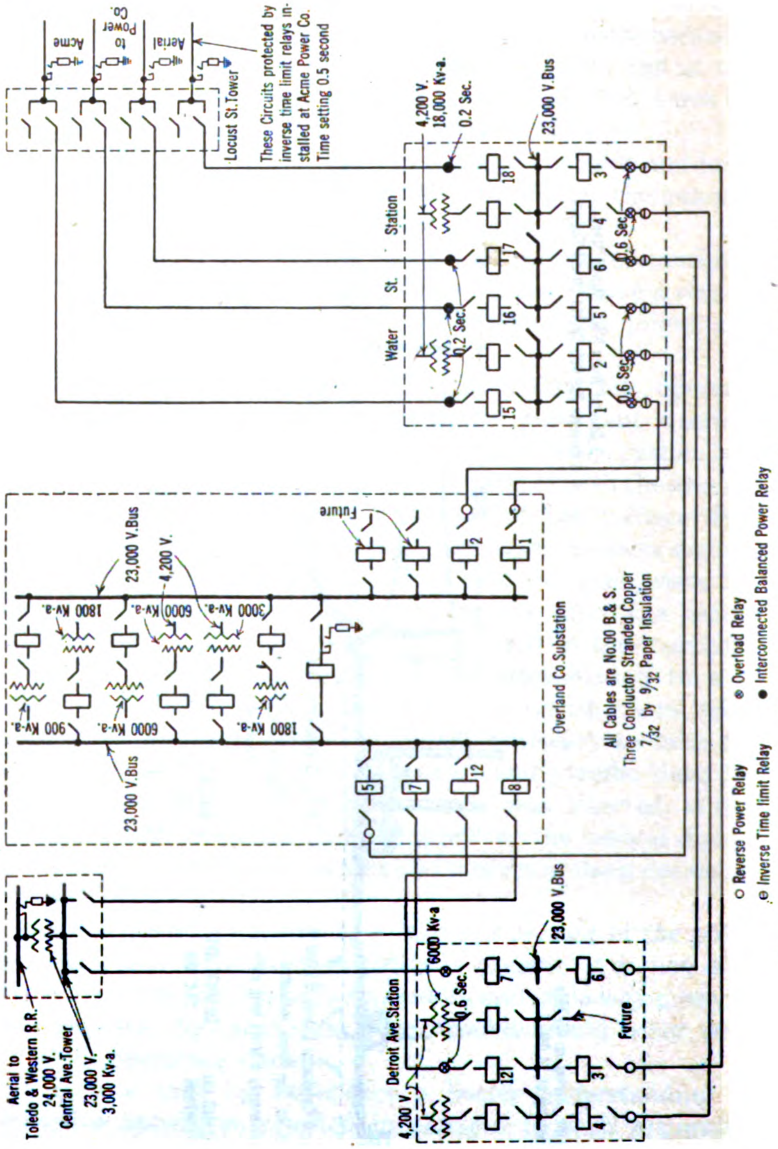

FIG 2—HIGH-TENSION SYSTEM OF THE TOLEDO RAILWAYS & LIGHT CO.

Fig. 2 is a one-line diagram of the system, showing protective apparatus.

Fig. 3 is a detail of the landing tower of the river crossing.

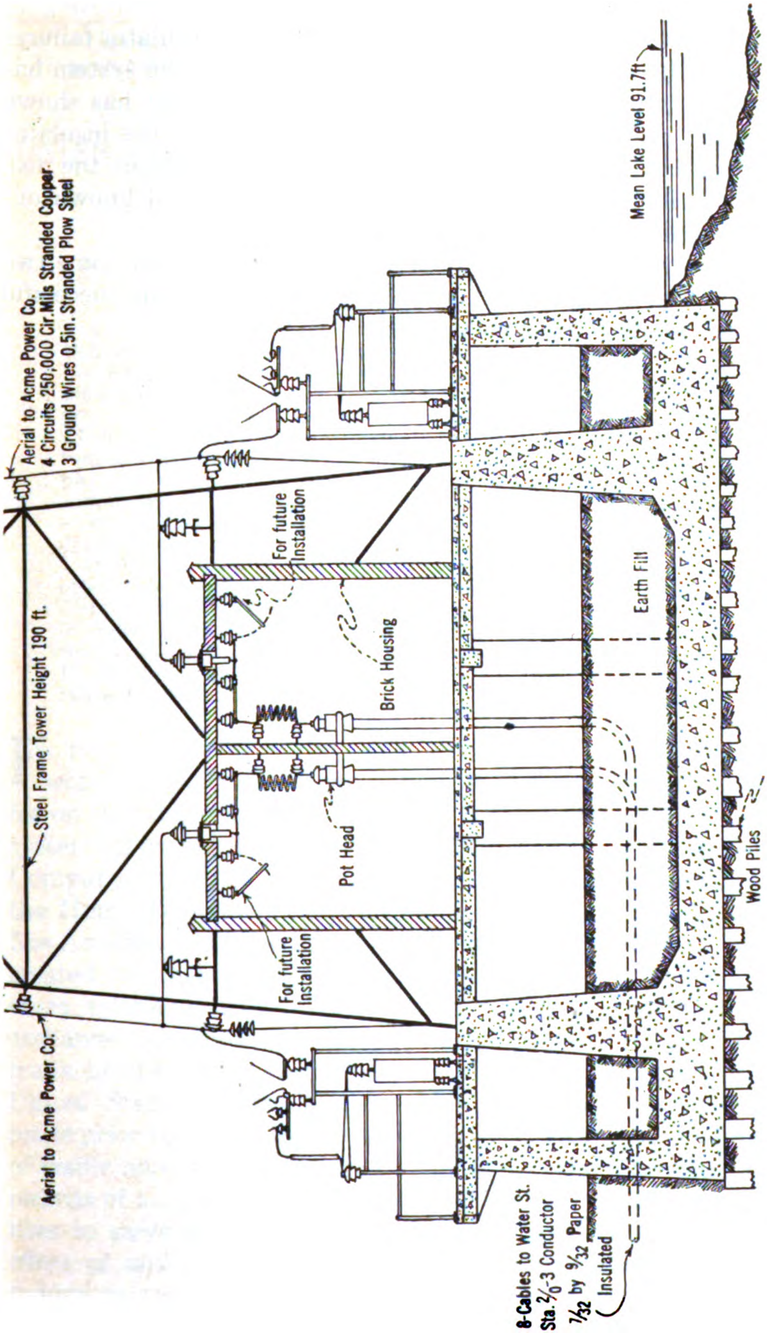
Aerial to Acme Power Co.
4 Circuits 250,000 Cir.Mils Stranded Copper.
3 Ground Wires 0.5in. Stranded Plow Steel
Mean Lake Level 91.7ft
Steel Frame Tower Height 190 ft.
For future Installation
Brick Housing
Earth Fill
Pot Head
Wood Piles
For future Installation
Aerial to Acme Power Co.
8-Cables to Water St. Sta. 2/0-3 Conductor 7/32 by 9/32 Paper Insulated

FIG. 3—SECTION AT BASE OF TOWER NO. 1

With reference to this crossing, it might be interesting to note that no trouble has been experienced by insulator failures due to lightning or other causes. This part of the system has passed through some severe lightning storms, but has shown no sign of weakness, due largely to the fact that the insulator values are about 200 per cent above working voltage, the disk type being used on the short spans, and the well known oil-insulated wood strains for the long spans.

The system has been in successful operation now some two years and is considered by this company as being successful in all points of construction.

Presented at a Section Meeting of the American Institute of Electrical Engineers, San Francisco Cal., February 7, 1919.

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UNIFICATION OF THE MANUAL AND AUTOMATIC TELEPHONE SYSTEMS

BY D. E. WISEMAN

Abstract of Paper

A description is given of the physical consolidation of the Bell manual and the Automatic Electric telephone systems of Los Angeles, Cal., which previously to June 1, 1918 operated as separate systems. While similar consolidations had been made previously they included relatively small volumes of traffic and afforded no engineering precedents as a guide to the consolidation of two systems serving 129,000 stations. The plans for the physical union of the two companies were devised by a joint committee of engineering representatives, and contained a number of novel operating and construction methods which are described.

Under the new system each subscriber has access to every other subscriber in the Los Angeles exchange and to all long-distance lines centering there. Where duplicate services were installed the subscriber was given his choice as to whether he would retain the manual or the automatic system, and about 12,500 duplicates were eliminated, the choice between the two types being equally divided.

IN telephone engineering and the resultant physical and economic accomplishment, June 1, 1918 figures prominently, for on that date the formal union of the Bell manual telephone system operated by The Pacific Telephone and Telegraph Company, and the Automatic Electric system operated by the Home Telephone and Telegraph Company in the City of Los Angeles, was effected under the management of the newly created Southern California Telephone Company, giving to every telephone user in that area a unified and unrestricted exchange telephone service and universal service over toll trunk lines to some eleven million telephones throughout the United States. Consolidations of this character have been made prior to this date but involving relatively small volumes of traffic and simple operating methods so that there were no records of actual performance or established engineering practises to serve as a precedent and guide for determining the effect of and the physical requirements necessitated by the sudden release of two large, distinct and separately bound volumes of traffic into a common channel.

Because of the novel operating and construction methods and the speculative possibilities involved in the important pioneering work of welding these fundamentally different telephone switching systems into a single eighteen million dollar plant serving 129,000 stations, a semi-technical summary of the events has been prepared for general information.

A brief reference to the conditions which brought about the consolidation will be made in order to better understand the problems that confronted the two competing telephone companies and their subscribers. Believing that competition instead of control was the automatic remedy to apply to public utilities, the City of Los Angeles invited telephone competition about sixteen years ago and then struggled along with her business firms and many of her residents paying two telephone bills for a divided and what proved to be an unsatisfactory telephone service. This condition was continued until the year 1916, when the public decided by popular vote to bring about an end to dual telephone service. Negotiations were begun and various proposals were considered by all concerned in an effort to avoid any waste or arbitrary measures. A plan was finally accepted for the organization of a local telephone company, which was to purchase the properties of the existing operating companies and unify the service, continuing with the equipments then in plant and giving the right to the telephone users to determine for themselves whether they would retain their automatic stations or manual stations. War conditions imposed restrictions in the conservation of materials and men for such projects and called for a careful weighing of the expected benefits and expenditures of materials and labor.

With this clear understanding of the requirements, a joint committee of engineering representatives was appointed to determine the methods for the physical joining of the two systems. As a result of their efforts, a fundamental plan, together with preliminary estimates of cost, was submitted and formally approved by the City of Los Angeles, the Railroad Commission of the State of California and by the Attorney General for the Federal Government, and on May 1, 1917, formal authorization was given to proceed with the project.

In order to picture the plants as they existed prior to the consolidation, I shall refer briefly to the physical properties and the operating methods of the two systems. Referring for a moment to Fig. 1, the area served by the duplicate plants was about 200 sq. mi. and lying within the corporate city limits. The open and solid circles show office and wire centers of the Home and Pacific Companies respectively, while the dotted and solid lines mark the areas of the respective districts. The Pacific Company was established first and the opening and location of its offices followed the telephone development of the city. The first office was located in the business area and as the population increased and spread to outlying districts, new offices and districts were established. Each office was located as near as practicable to the center of the wire distributing system as determined by a study of the existing plant and expected growths for 15 or more years hence. As years

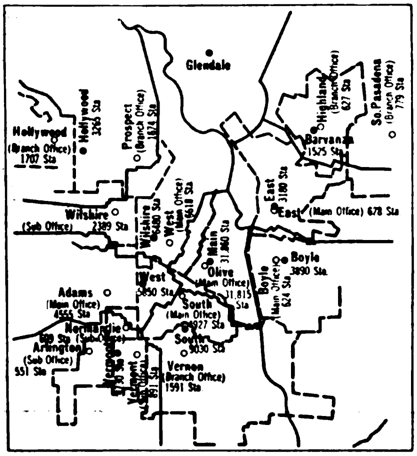
Glendale
Hollywood (Branch Office) 1707 Sta
Hollywood 3265 Sta
Prospect (Branch Office) 1674 Sta
Highland (Branch Office) 627 Sta
So. Pasadena (Branch Office) 779 Sta
Barvanza 1575 Sta
East 3180 Sta
East (Main Office) 678 Sta
Wilshire (Sub Office) 2389 Sta
Wilshire 6480 Sta
West (Main Office) 16610 Sta
Main 31,860 Sta
Olive (Main Office) 31,815 Sta
Boyle 3890 Sta
Boyle (Main Office) 624 Sta
West 5850 Sta
Adams (Main Office) 4565 Sta
South (Main Office) 6927 Sta
Normandie 600 Sta (Sub Office)
Arlington (Sub Office) 551 Sta
South 9030 Sta
Vermont 1730 Sta
Vermont (Sub Office) 891 Sta
Vernon (Branch Office) 1591 Sta

FIG. 1—AREA SERVED BY DUPLICATE PLANTS

go by and old offices are outgrown studies very often show an economy in subdividing the original district or changing the boundaries so that this natural process tends to correct any errors in estimates of growths and locations of such expected growths.

May 1, 1917, the Pacific Company's exchange consisted of its standard outside plant and station equipment and nine manually-operated central offices serving about 69,000 stations. Bell equipment was used in units having a capacity of 9600 multiple lines. Telephone connections were established generally by the calling subscriber removing the receiver from the switch hook, causing a light to appear before an answering *A* operator, who upon receiving a request for a particular number cut-in on an order wire to the particular switchboard unit in the district, indicated by the prefix of the number called-for. An operator at the distant switchboard unit, assigned a trunk over this order wire to the calling *A* operator and completed the connection by plugging into the called-for subscriber's multiple. Fig. 2 shows a schematic transmission circuit of a typical connection. The operation of this circuit will be described later and in connection with the unified plant.

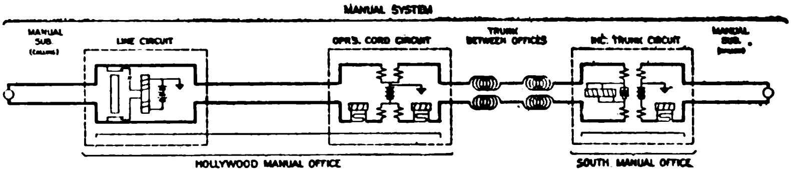

FIG. 2—EQUIPMENT INVOLVED IN A CONNECTION BETWEEN A HOLLYWOOD OFFICE MANUAL SUBSCRIBER AND A SOUTH OFFICE MANUAL SUBSCRIBER

The former Home Company operated an automatic exchange including a parallel and similarly constructed outside plant and fourteen offices serving a total of approximately 60,000 stations. About 35,000 stations were equipped with dials and approximately 25,000 manual stations operated from private branch exchanges and as public pay stations. The lines from the manual stations terminated on a 45-position manual switchboard in the Olive Office. Calls from automatic stations to automatic stations were made by dialing five or six digits, as required, to reach the particular district and individual subscriber. In capacity the former Home Plant was one of the largest and probably the most successfully operated of any automatic system installed in the United States or abroad. Home Company private branch exchange subscribers were reached by dialing the private branch exchange operator, who completed the connection. Calls outgoing from private branch exchange subscribers were trunked to the man-

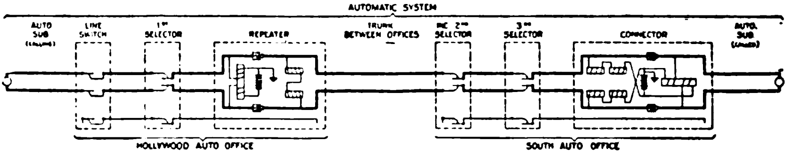

FIG. 3—EQUIPMENT INVOLVED IN A CONNECTION BETWEEN A HOLLYWOOD OFFICE AUTOMATIC SUBSCRIBER AND A SOUTH OFFICE AUTOMATIC SUBSCRIBER

ual transfer board above mentioned, the calls coming in on an automatic traffic distributor which placed each line lamp signal before a non-busy operator. The operator upon taking up these connections would complete the call direct if to another private branch exchange station through the subscriber's multiple or dial the number required, if an automatic station was wanted. Fig. 3 shows a schematic transmission circuit of a typical full automatic connection. The operations and functions will also be described step by step later.

Los Angeles has had the distinction of having more telephones per capita than any other city in the world and is now very close to the top of the list. This general usage is reflected in the number of calls originating in each system, as shown by the records of traffic. The approximate numbers of daily average calls originating in the former Pacific plant and Home plant were in the vicinity of 430,000 and 420,000 respectively.

The engineering problems demanded, therefore, a reasonably close approximation of the volume of existing and added traffic which could be expected to flow between the groups of stations of the various districts of the two plants; a determination of the most direct and economical routing of such calls based on efficient operating methods and the use of existing facilities; and the design and development of an inter-unit trunking plant and switching circuits necessary to maintain the commercial standards for transmission and supervision between the two systems regardless of the mechanical, electrical and operating inequalities. Visual and audible signals peculiar to the separate systems required for supervisory purposes needed to be synchronized or harmonized and extended when necessary so as to afford common usage.

It is obvious that a great many plans and combinations of plans for unification were developed in sufficient detail to determine their relative capital and operating costs and advantages and disadvantages. The plan in principle that was adopted for handling the inter-office traffic between the systems was to operate all existing offices as units of the complete exchange and route the new automatic or manual trunks of each office into the adjacent office of the opposite system, where the connection could be completed by the most direct method and route.

Having referred to the facts that were most vital in shaping the project, I should like to outline the organization and schedule of work involved in the construction program estimated to cost $1,250,000. Every reasonable effort was demanded to bring about a unification of the properties without waste of time, and accordingly a complete schedule for the ordering of materials, manufacturing, assembly and installation thereof was set up after a canvas of probable material deliveries and of the labor situation. It became evident that a period of twelve months would be the shortest time possible to complete the necessary work, keeping in mind that war demands might upset the schedule, and all effort was centered on finishing the project within the minimum time. Specifications and plans were completed for each individual project, numbering all together about 110, and each one was charted with due regard to the materials involved, quantity, desired time of delivery and installation and its relation to the project as a whole. Fig. 4 shows a typical group of projects and illustrates the method of maintaining the schedule for the whole program. As items of material were, of course, duplicated in a great many of the specifications, a master chart was prepared showing the total quantities of each of the thousands of items required at specified dates.

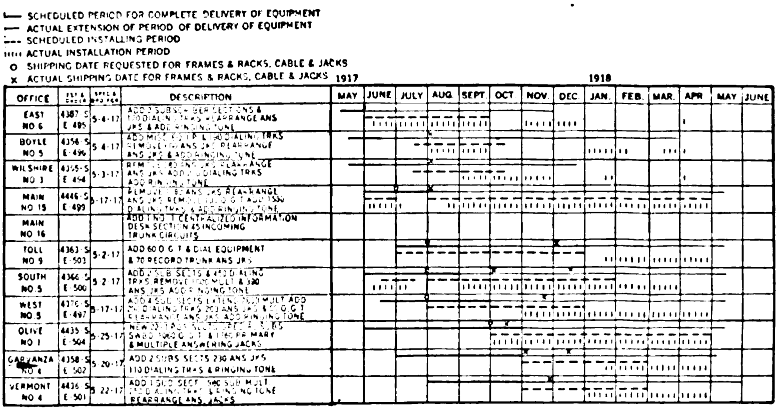

FIG. 4—DIAGRAM SHOWING METHOD OF MAINTAINING SCHEDULE FOR THE ENTIRE RECONSTRUCTION

The largest single project consisted in the design and manufacture of the 66-position special tandem switchboard and associated equipment to be located in Olive Office for the translation and distribution of calls from automatic stations to manual stations in the downtown area. This switchboard, together with the switching circuits were designed in detail by the engineers in the general office of the telephone company, and all of the manufacturing and assembly work was performed in San Francisco. Extensive rearrangements of the Olive office building were necessary to provide space for this equipment and for retiring quarters for the large number of operators required to give the necessary 24-hour continuous service. Fig. 5 shows the floor plan arrangement of this switchboard and associated operating room space.

In the manual offices it was necessary to equip the regular subscriber positions with a dial for sending out the electrical impulses, and to provide outgoing trunks connecting directly with the automatic equipment in the adjacent office. There were approximately 375 subscriber switchboard positions in the manual system in the Los Angeles exchange that required the installation of this special equipment and associated wiring and this proved to be one of the most difficult parts of the work, because such work had to be performed on positions of switchboard that were in continuous operating service. I will refer to Fig. 6 and describe the switching circuit associated with the dials at the operators' positions. Each operator on the subscribers' switchboard is provided with 10 outgoing trunks terminating in the nearest automatic office on first selectors. These outgoing trunks are provided with twin jacks, one above the other, and electrically connected so that the dialing device can be associated with each of the trunk circuits to the distant

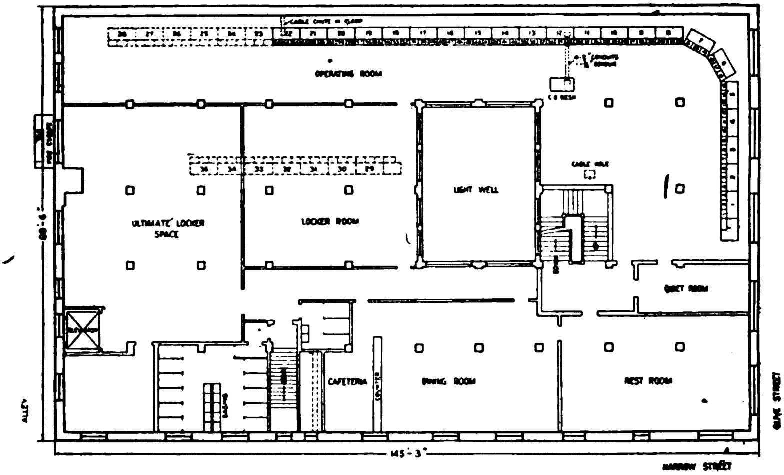

FIG. 5—PLAN OF SECOND FLOOR OLIVE OFFICE, LOS ANGELES, CAL.

office. The plug connecting with the dial is inserted in the lower first jack while a call originated by a manual subscriber for an automatic station is connected to the upper first trunk jack by means of the regular *A* operator's doubled-ended cord circuit. The operator then proceeds to dial the number requested and as soon as this number has been dialed, the operator moves the dial circuit plug to the lower second jack, thereby pre-selecting the trunk circuit for the next call for an automatic station. The operation of the second and third selectors and final connector is the same as described later under "Automatic to Automatic Connections." The circuit is so arranged that the manual *A* operator just referred to receives direct supervision for both the calling manual and the called for automatic station. At the end of the conversation, the lighting of a lamp associated with each end of the *A* cord circuit indicates to the operator that the connection has been finished and all cords are to be cleared from the subscriber's line and trunk jacks. The outgoing dial trunks are used in rotation and the actual number of the trunks connected by such lines to the distant office varies with the traffic requirements.

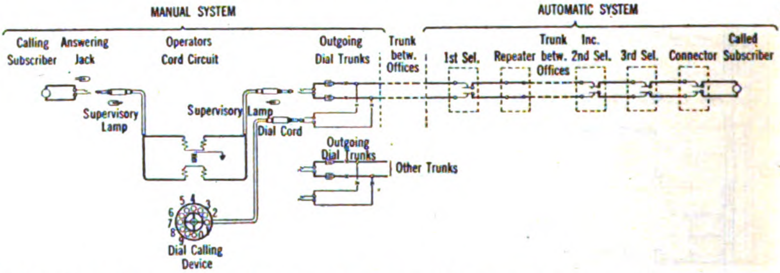

FIG. 6—METHOD OF ESTABLISHING A CONNECTION BY MEANS OF A DIAL CALLING DEVICE

Central office telephone installation work has generally been organized for individual projects usually confined to a particular office building. The plan of scheduling the material and utilizing this material to its greatest advantage made it necessary to depart from the regular practises of the installing forces and to provide that all of the work should be treated as one project wherein the men trained for specific work were to be moved from one office to another as materials arrived and thereby facilitating the completion of the work regardless of irregularities in the arrival of materials for a particular office.

This arrangement was one of the important factors in effecting the final completion of the central office work April 30, 1918. The time intervening from the date until the beginning of the delivery of the directory and the formal announcement of consolidation on June 1, 1918 was required in placing thousands of test calls over all combinations of connections to make sure of positive operation. In a typical connection between an automatic and manual station there are 41 relays, and 79 from manual to automatic, having movable parts controlling from one to ten electrical contacts, each of which must function in the proper sequence from the start to the completion of each telephone call. I do not wish to convey an impression that telephone circuits are inherently subject to failure because they are not. The characteristics and operating requirements for each relay, for instance, is known mathematically and what it can be depended upon to do for a specific period of time. At regular intervals each type of relay is given its proper current adjustment using measuring instruments designed for that purpose.

The installation of telephone cables and central office equipment of the manual or automatic type required the use of highly trained and skilled labor and the Telephone Company faced the difficulty of obtaining the large number of electricians and mechanics required to hold the schedule and training them for the special work. As it was, considerable overtime became necessary to maintain a working balance between the arrivals of material and the available labor.

Among the larger items of expenditure, and one involving months of study and calculations in voice transmission were the additions and changes necessary in the cable trunking plant in order to maintain commercial standards on all local and long distance connections. These studies included the use of and application of loading coils to the former Home Company cable plant amounting to about 1000 coils and the addition and respacing of many of the coils in the portion of the Pacific Company cable plant. All together about 75,000,000 conductor-feet of various gages of underground telephone cables were ordered and installed to provide new routes and reinforce existing trunk groups required for the consolidated service.

Prior to the consolidation, practically all of the subscribers having private branch exchanges maintained duplicate switchboards and station apparatus. The problem, therefore, of consolidating this type of equipment offered no particular difficulty, as such consolidations could be and were effected by grouping the trunks formerly serving the separate systems on the particular switchboard to be retained, adding thereto the amount of line and trunk facilities desired by the subscriber and eliminating the duplicate switchboard and stations not required. The net effect was to remove about 345 single-position private exchange switchboards from the system. In the case of several of the larger commercial companies, it was necessary to order complete multiple private branch exchange switchboards of the 640-line capacity and about 30 sections of such boards were placed in service as fast as the equipment could be engineered and manufactured. It will be interesting to note that the flow of traffic to and from private exchanges was not greatly disturbed from the existing paths by this plan of consolidating; a principle which was kept well in mind and taken advantage of wherever practicable.

Where individual and party stations were duplicated, both stations were left connected until the new directories were delivered, at which time the subscriber was requested to use the telephone of the particular system that he had made application for and the other station was removed as soon as the construction forces could handle the work. Approximately 13,000 duplicate stations have been removed.

A considerable number of operators were required and for a while it looked very much as if the consolidation would have to be postponed because of the inability to obtain the needed force. Good service depends to a large extent on capable and efficient operators and you can appreciate the difficulty that confronted the operating department in the selection, employ and training of approximately 500 additional operators required for handling the special transfer switchboard installed in the Olive Office building, and for the large number of added positions of switchboard in the various manual offices. A large operating school equipment was hurriedly manufactured and installed and training of operators was started about the first of the year 1918. The schedules also provided for the early installation of dials on the subscriber positions in the manual offices for advance training of the regular operating force. Special observation equipment was designed and furnished for practise work in placing test calls and later for supervision in determining and checking the accuracy of dialing the calls placed by the subscribers. By means of automatic recording devices the numbers called for by subscribers or instructors were compared with the numbers actually dialed and in this way the operating force was gradually brought to an efficient basis by the time the construction work was completed.

Proceeding under the restrictions that each subscriber having duplicate service should determine for himself whether to retain automatic or manual substation equipment, the Commercial Department carried on a vigorous campaign to obtain these subscriber's choices and to arrange accordingly. I do not have the exact figures but I understand that of the 18,680 duplicate stations about 5200 duplicates were retained and the balance were divided evenly between the two types. The expected result of this canvass had been forecasted and was an essential factor in engineering and in construction work.

As a function of the commercial canvass the Directory Department was confronted with the necessity of recasting the entire directory scheme to fit the particular needs of a unified service. A great amount of thought was given to the determination of the most efficient arrangement of listing and numbering subscribers, and while this seems trivial yet a careless directory arrangement reflects on the quality of the telephone service and robs the public of valuable time. Many number changes were involved and a complete relisting of every subscriber's name and number into one alphabetical list introduced great possibilities of errors. (It is a matter of passing interest that 165,000 copies of the directory were issued and distributed in Los Angeles and to other exchanges for long- and short-haul toll traffic and that over 441,000 pounds of paper were required in the printing of the consolidation issue.)

In the present unified plant, local calls are divided into four main groups and are obtained in the following ways:

Calls from Automatic Stations to Automatic Stations are obtained in the same manner as under the former Home management, that is, by the subscriber dialing the number wanted as indicated by the directory listing. Such subscriber sets are provided with the familiar dialing device arranged to transmit from one to ten electrical impulses for each "pull" of the dial. In the automatic system most of the stations are reached by dialing five digits although there are a few thousand six digit numbers. The operation of the first digit of the five digit numbers selects the office district required, the second digit selects the particular thousand, the third digit selects the particular hundred, while the fourth and fifth digits select the tens and unit respectively of the number desired. Referring to Fig. 3, the calling automatic subscriber upon removing the receiver from the switchhook completes an electrical circuit through a Keith line switch, the chief function of which is to direct the simultaneous calls to a minimum number of trunks to first selectors. Each automatic line therefore terminates on a primary line switch having ten paths to as many first selectors, these trunks being multipled to other line switches, depending on the calling rate or traffic load of the particular group of lines. The operation of the first digit of the number wanted causes the mechanism of the first selector to step the brush terminals upward to one of the ten levels arbitrarily connecting to a particular 10,000-line unit. This selector is of the trunk-hunting type, that is, the subscriber, as noted above, having dialed, say, the digit 6, causes six electrical impulses to be transmitted through the selector mechanism through the stepping relay, raising the brushes to the sixth level. The selector then automatically begins a rotary movement and continues until an idle trunk is found. There are ten trunks over which this rotary trunk selection takes place and the traffic is so distributed over selector equipment that with very few exceptions an idle trunk will be found within this group of ten. The connection is then established through what is termed repeater equipment (consisting of coils and relays by the aid of which the calling impulses are repeated from the local to the distant office and talking battery is provided to the calling station) to a particular second selector in the distant office. The dialing of the second digit by the calling subscriber again operates the stepping mechanism to one of the ten levels corresponding to the thousands of the number wanted. Automatic rotary movement takes place, selecting an idle trunk to the third selector where the dialing and selecting of the hundreds is the same as for the first and second selectors. The connection now is established through to the connector which is similar in its operation to selectors with the exception that the tens digit steps the mechanism to the corresponding level while the units digit controls the rotary movement to the particular unit required. The connector also supplies talking battery to the called subscriber and sends out the necessary ringing impulses to call either the individual or party subscriber desired or sends back the busy signal if the line called is in use. The restoring of the receivers to their switchhooks automatically returns all of the connecting equipment to normal position again for use on subsequent connections.

Calls from Automatic Stations to Manual Stations are obtained by operation of an arbitrarily assigned digit, the ninth digit or level being available in this case. Trunks from these first selector ninth levels lead the nearest manual office and terminate by the aid of the familiar line and cutoff relay on an answering jack with a lamp signal before an *A* operator. Referring to Figs. 7 and 8, the *A* operator upon receiving a line lamp signal, plugs into the corresponding answering jack and requests the subscriber to give the number (and office prefix) wanted as shown by the directory listings. The call is then completed within the office received or is trunked over the manual trunking system to the distant *B* operator in the same manner as described under calls manual to manual. In the downtown district where a considerable amount of traffic is involved, it was found impossible to add to the large number of *A* positions to the various manual units and it was necessary to install a special manual switchboard, shown in Fig. 5 in available space in the Olive office building. This special board contains only the necessary multipled terminating lines, outgoing trunks and key and supervisory equipment necessary for establishing the connections between the automatic and manual system. Automatic calls therefore in this district are completed by the dialing of the digit 9 as before, bringing the line signal in on this special *A* switchboard where such con-

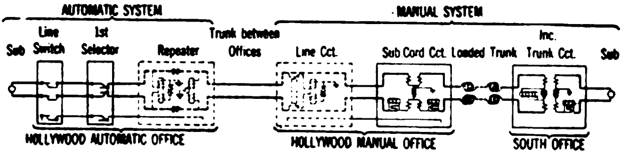

FIG. 7—EQUIPMENT INVOLVED IN A CONNECTION BETWEEN A HOLLYWOOD OFFICE AUTOMATIC SUBSCRIBER AND A SOUTH OFFICE MANUAL SUBSCRIBER

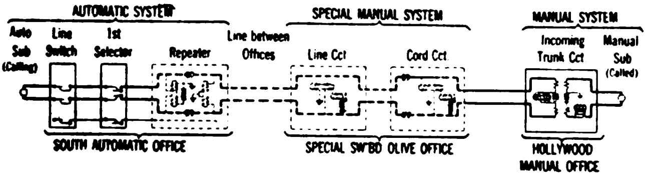

FIG. 8—EQUIPMENT INVOLVED IN A CONNECTION BETWEEN A SOUTH OFFICE AUTOMATIC SUBSCRIBER AND A HOLLYWOOD OFFICE MANUAL SUBSCRIBER

nections are completed as in regular manual practice over trunk lines assigned over order wires.

Calls from Manual Stations to Manual Stations are obtained in the same manner as existed prior to the consolidation, that is, by the agency of the *A* and *B* operators and corresponding manual switchboards. Referring to Fig. 2, the calling manual subscriber upon lifting the receiver from the hook causes a lamp to light before an *A* operator in his district. This line terminates on the ordinary line and cutoff relays, the former operating as soon as the switchhook closes the circuit, causing the line lamp to burn. The *A* operator then plugs into the corresponding line jack with one end of a double-ended cord circuit, this operation causing the cutoff relay to energize and thereby opening the circuit through the line relay and lamp. The operator then throws the listening key and requests the called for number. She then proceeds to complete the connection by plugging either directly into the subscriber multiple or by plugging into a trunk line leading to the distant office required and as assigned by the distant *B* operator over an order wire circuit. The distant trunk operator then plugs into the required subscribers' multiple and automatic ringing proceeds until the subscriber answers. Supervisory lamps associated with both the trunk cord and the double-ended *A* cord furnish the necessary indication to the operators of the establishment of the connection and end of the conversation. When both lamps associated with the double-ended *A* operator's cord relight, the connection is taken down and this operation gives a disconnect signal also to the distant trunk operator.

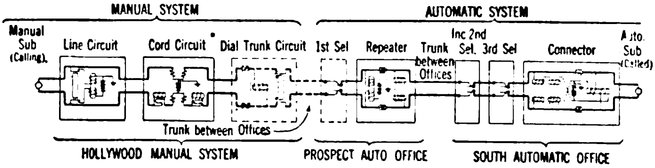

FIG. 9—EQUIPMENT INVOLVED IN A CONNECTION BETWEEN A HOLLYWOOD OFFICE MANUAL SUBSCRIBER AND A SOUTH OFFICE AUTOMATIC SUBSCRIBER

Calls from Manual Stations to Automatic Stations are obtained by direct trunk circuits. An *A* operator receiving a manual subscriber's request for a particular automatic number, as indicated by the directory listing, proceeds to dial the number in the same manner as described above for an automatic subscriber. Each *A* operator is provided with a group of trunks, as shown by Fig. 6 and described in the first part of this paper, leading to the nearest automatic office and terminating directly on first selectors.

Private Branch Exchange Calls originating from such exchanges of the former Home Company were formerly operated and are still operated on a manual basis. Calls placed by extension stations from these private exchanges are trunked to a manual switchboard in the Olive office building, this switchboard having the familiar subscriber multiple of all the private exchange trunk lines. The incoming private exchange trunk lines, however, are carried through Keith line switches, the function of which is to select a non-busy operator and to place the line lamp signal before that operator. This arrangement is commonly known as the traffic distributor. This pre-selected operator then receives the request for either an automatic or manual number and if for the former, she dials the number as described above for manual *A* operators. If the called for number is for another private exchange station, the operator completes the connection in the multiple similar to a manual-to-manual connection and if the request is for a station in a manual office, it may be obtained by the use of order wires and trunks direct to the office required or over trunk lines to the special Olive office manual *A* board. All connections to and from the former Pacific manual private branch exchange stations are completed in accordance with the above general methods of handling calls to and from manual stations

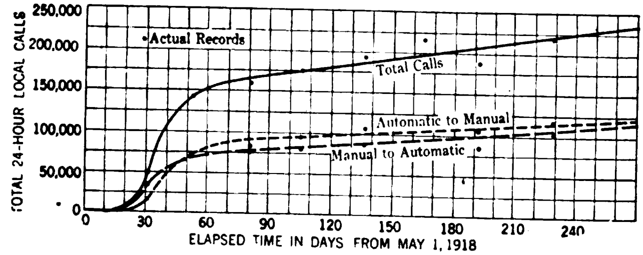

Fig. 10—Curves Showing Tendency of Originating Calls Between Former Pacific and Home Stations

Fig. 10 has been prepared to indicate the volumes of traffic expressed in calls that passed between the former automatic and manual stations as at the specified dates. The curve was developed from the following records and immediately after the record of September 13, 1918. (Later records have since been taken and are shown by dots on the original curve.)

	Automatic to Manual	Manual to Automatic	Total calls
May 31, 1918 (1 day before formal announcement)	16,308	31,870	48,178
June 21, 1918	71,883	70,921	142,804
July 19, 1918	83,589	76,556	160,145
August 23, 1918	95,059	80,285	175,344
September 13, 1918	105,602	88,161	193,763

So far as I know, no definite statement can be made as to the gains accruing to the subscribers at Los Angeles under the consolidated arrangement, because the most important factors are not capable of reduction to equated savings in dollars.

Some of the major factors resulting in direct benefit are:

1. Value to the subscribers resulting from telephone access to each and every subscriber in the Los Angeles exchange and to all long distance lines centering there.
2. Rental savings resulting from the elimination of a large number of duplicate stations and private exchange switchboards.
3. Elimination of the indirect economic loss due to confusion and community service inefficiency of separate telephone systems.

Some of the factors which tend to offset part of the savings are:

1. Added annual charges on the plant and equipment required to provide means for universal service. There was very little elimination of duplicate plant investment primarily because each plant was designed to care for a definite development and volume of traffic. Consolidation obviously does not reduce traffic volume, but because the telephone field is considerably increased to every subscriber, the total volume of traffic in the consolidated plant is substantially increased.
2. Added operating and maintenance costs.

From a careful weighing of these factors it is manigest that the consolidated plant offers substantial savings and benefits over the dual systems. The worth of a telephone system to any community lies, not only in its capacity for effecting good service but that such service shall be universal and available to the maximum possible number of local and distant subscribers.

To be presented at the Pacific Coast Convention of the American Institute of Electrical Engineers, Los Angeles, Cal., September 18-20, 1919.

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(*Subject to final revision for the Transactions.*)

CALIFORNIA 220,000-VOLT — 1100-MILE — 1,500,000-KW. TRANSMISSION BUS

BY R. W. SORENSEN, H. H. COX AND G. E. ARMSTRONG

ABSTRACT OF PAPER

This paper summarizes the power resources of California and the probable loads to be supplied within the next six or seven years. For the purpose of economically distributing the necessary power and supplying the load, a long high voltage transmission line is proposed. As this line would interconnect a number of different companies, it assumes the nature of a bus bar. The authors show how the proposed line may link with some of the lines now in service and enumerate the advantages of such interconnection. A comparison is made between the 240-mile Big Creek line now operating at 150,000 volts, 50 cycles, and the operation of this line at 220,000 volts, 60 cycles. Operating data on the Big Creek line are shown to indicate the character of the construction necessary for California conditions. Conclusions are drawn as to the particular features to be observed for successful operation of 220,000-kv. lines.

INTRODUCTION

FUELS, particularly oil, must soon be used for isolated power only in places where electric power is not available, as in the propelling of air and ocean craft. In large power systems, especially in the West, the use must be limited to standby service, for peak loads, low water periods, and other emergencies.

POWER RESOURCES

California has available ample hydroelectric power to supply the industrial and agricultural demand for many years.

Small developments aggregating 325,000 kw. have been completed and many others of this type are available. There are also four large projects as indicated in Table I. which can readily be developed to a capacity of 1,500,000 kw. in the near future.

The data for the following tables of resources and loads, of the Northern part of the state, are taken from various reports

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Manuscript of this paper was received August 5, 1919.

which have been published and no attempt has been made to verify them.

TABLE I—LARGE POWER RESOURCES

	Now Developed and Under Construction	Proposed Developments 1926	Reasonable Future Development (Not Ultimate Capacity)
	kw.	kw.	kw.
Pitt River	None	200,000	500,000
Feather River	100,000	200,000	300,000
Big Creek	100,000	300,000	500,000
Colorado River	None	None	200,000
Total	200,000	700,000	1,500,000

Total 1926 hydroelectric power development including small projects is 1,025,000 kw.

LOAD DEMAND

The best available information indicates a demand in 1926 approximately as shown in Table II.

TABLE II.

1.	Sacramento Valley, northern portion	70,000 kw.
2.	Truckee River electrification	40,000 "
3.	Sacramento Valley, southern portion	125,000 "
4.	San Francisco Bay District	250,000 "
5.	Fresno District	90,000 "
6.	Bakersfield District, including Tehachapi electrification	125,000 "
7.	Los Angeles District	300,000 "
8.	Barstow and Needles District, including railroad electrification	40,000 "
	Making a total of	1,040,000 "

In order to carry this load, approximately 500,000 kw. additional in hydroelectric capacity will be required.

A demand for power such as shown in Table II can be supplied most economically by power developed in large units. Large power units require transmission lines of the highest possible economic voltage.

*It has been shown that, for long transmission, 220,000 volts is economical under conditions which require a much more expensive construction than has proven adequate for the 150,000-volt lines of the Southern California Edison Company.

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*Silver, *Problems of 220-kv. Power Transmission*, A. I. E. E. PROCEEDINGS, June, 1919.

CALIFORNIA TRANSMISSION BUS

On this basis, a plan as shown on the map, Fig. 1, is proposed. In this plan the interconnection of all the California Power Companies has been assumed, as an economic necessity for its best utilization. Interconnections of limited capacity are not entirely satisfactory because they fail just at the time they are needed most to transfer from one system to another large blocks of power.

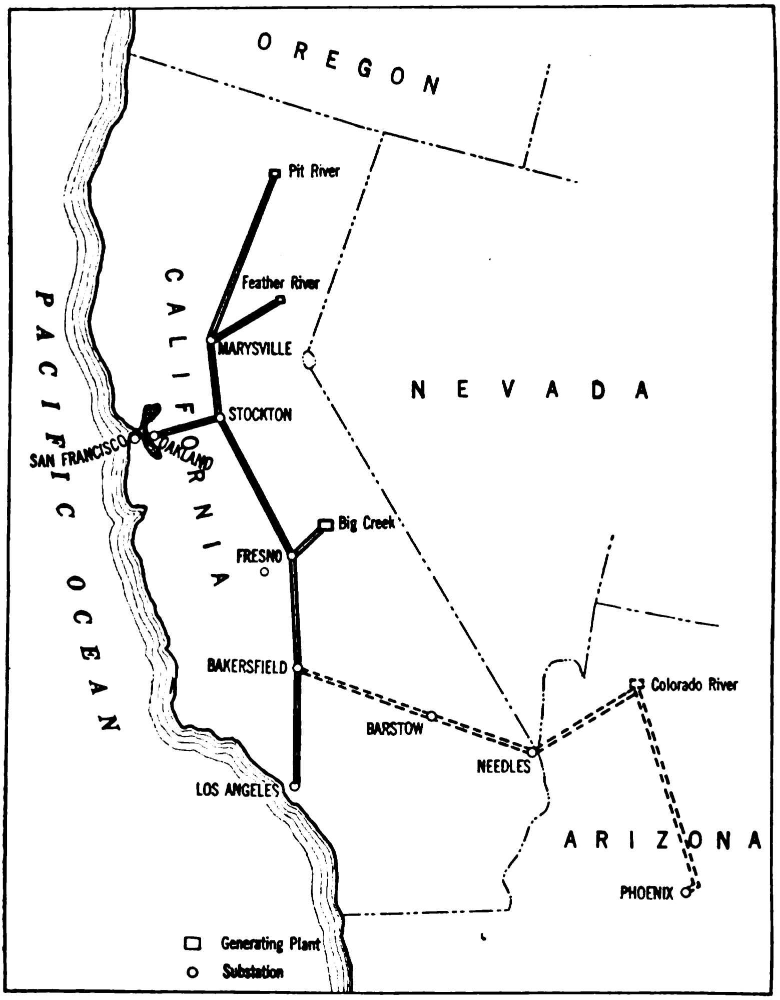

FIG. 1—CALIFORNIA 1100-MILE—220 KILOVOLT—TRANSMISSION BUS

The plan of the proposed scheme involves the construction of a two-circuit transmission system extending from Pitt River to Los Angeles, a distance of 570 miles. Branch lines of like voltage connect the three other power projects and the San Francisco load center to this main line on which the other load centers are located. The main line thus becomes a high-tension bus extending nearly the entire length of the state, hence its name; California Transmission Bus. This arrangement makes possible unlimited interconnection and exchange between all the power companies of the state.

Substations have been located at Marysville, Stockton, San Francisco, Fresno, Bakersfield and Los Angeles. These points are natural load centers and suitable points for connecting with the present power systems. On the Colorado River branch, the construction of which is dependent upon the electrification of the transcontinental railroads, substations would probably be located at Barstow and Needles. The substations divide the lines into sections of suitable length for practical operation, the longest section being 150 miles, as shown in Table III.

TABLE III.

Pitt River to Marysville	150	miles
Feather River to Marysville	60	"
Marysville to Stockton	90	"
Stockton to San Francisco	60	"
Stockton to Fresno	130	"
Big Creek to Fresno	40	"
Fresno to Bakersfield	100	"
Bakersfield to Los Angeles	100	"
Bakersfield to Barstow	110	"
Barstow to Needles	150	"
Needles to Colorado River	100	"
Colorado River to Phoenix	100	"
Pitt River to San Francisco	300	miles
Big Creek to Los Angeles	240	"
Big Creek to San Francisco	230	"

THE TRANSMISSION LINE

The standard frequency, 60 cycles, has been assumed on the basis that the Southern California power systems operating at 50 cycles will ultimately find it advantageous to conform to the A. I. E. E. standard. In the natural growth of the load as shown in Table II, 70 per cent of the 1926 load will be supplied by the 60-cycle systems. Interconnection of such large load centers or power sources through frequency changers, limits the exchange of power, is uneconomical, and increases tremendously the required operating vigilance.

The practicability of the high-voltage line has been well demonstrated by over five years of remarkably successful operation of the 150,000-volt lines of the Southern California Edison Company which, during this period have delivered from the Big Creek power houses over the 240-mile lines to the Los Angeles distribution system, 1,200,000,000 kw-hr. at an average efficiency of 87.5 per cent with a 45 per cent load factor. During this period there have been no interruptions for which the high voltage is responsible, and on the contrary, the system has been free from disturbance and interruption to a greater degree than the lower voltage lines in the same locality.

The present Big Creek lines can be operated at 220,000 volts, 60 cycles, without material change and this is proposed as a link of the transmission bus, and its operation under these conditions will be analyzed and applied to conditions of the proposed system.

Corona. As now operated, at 150,000 volts and 50 cycles, the voltage is only 80 per cent of the lowest critical voltage of any part of the line and there is no corona loss. At 220,000 volts, 60 cycles, corona loss occurs to some extent on the entire line but amounts to but 0.4 per cent of the line capacity during fair weather. With storm conditions over the entire line, and with an assumed reduction of 20 per cent in the critical voltage, the corona loss would be 8 per cent of the line capacity. This loss is not sufficient to make the line inoperative and would occur too rarely to be an economic factor.

Insulation. The Big Creek 150,000-volt lines have nine units in each suspension string and two eleven-unit strings in parallel on dead ends. During the five and one-half years of operation only two insulator string failures have occurred. Both of these were during normal conditions of operation without any apparent cause, other than that of being in a location where the insulators have been found to have a relatively high rate of deterioration.

The Big Creek line towers allow sufficient clearance to permit the lengthening of the nine unit suspension strings to eleven units, and to any desired number of units at dead ends. Table IV. shows safety factors for insulator strings, wet and dry.

The Big Creek line operated at 220,000 volts is at the critical corona voltage and any disturbances resulting in a higher voltage will quickly expend their energy in producing corona loss, which will permit a smaller safety factor to be used.

The curves in Fig. 2, showing arc-over voltage as reproduced from Mr. Silver's paper, *Problems of 220-kv. Power Transmission,* show no practical gain in dry arc-over voltage for strings of more than ten units, and with these facts in view it is proposed that for operating the Big Creek line at 220,000 volts, suspension strings have eleven units and dead end strings 12 units in series. Insulator testing crews have several times reported four and five defective units in a nine-unit suspension string, without any indication of trouble. The only apparent value of a longer string than that proposed would be a decreased probability of sufficient defective units in a string to cause breakdown. Developments of methods of grading insulator units and shielding insulator strings, will in all probability, materially change curves of Fig. 2.

Present day method of insulator testing and maintenance would probably have prevented the two failures which have occurred on the Big Creek lines as previously mentioned. These methods applied to the lines operating at 220,000 volts and the use of the better types of insulators now available will insure successful operation.

TABLE IV. SAFETY FACTORS FOR INSULATOR STRINGS

	Wet arc-over		Dry arc-over	
	9 unit String	11 unit String	9 unit String	11 unit String
(87 kv. to ground) 150 kv........	4.3		4.8	
(127 kv. to ground) 220 kv.......		3.7	3.3	3.4

Charging Current. Long high-voltage lines cannot be operated without synchronous condensers at the receiving station to regulate the voltage, and as a consequence the charging current, even at the standard 60-cycle frequency becomes a factor of no great importance as long as these synchronous condensers are connected to the line.

Without these condensers the line charging current must be furnished entirely by the generators, in which case the generators may become greatly overloaded and at the same time produce a very high voltage over which the operator has no control. To avoid this emergency a transmission line with its generators, transformers, and synchronous condenser must be considered as a unit and as such should be securely coupled together electrically at all times. This has been proved praccal in the case of the Big Creek system in which it is possible to start the 15,000 kv-a. condensers and bring them up to speed with the generators.

Line Capacity. The Big Creek lines as operated at 150,000 volts with 30,000 kv-a. condenser capacity per line at the receiver end are each good for 57,500 kw. at 85 per cent power factor and will have under these conditions a line drop of 11 per cent.

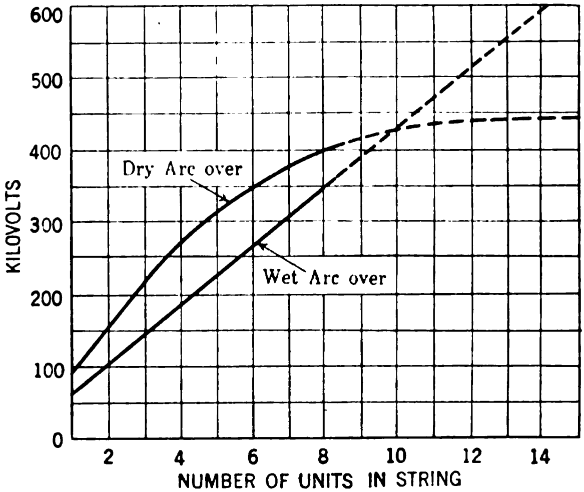

FIG. 2—TYPICAL 60-CYCLE ARC-OVER CHARACTERISTICS OF SUSPENSION INSULATORS

Operated at 220,000 volts these lines should each have a capacity of 125,000 kw. with an equal line drop when provided with the proper condenser capacity, which is approximately 75 per cent of the line capacity in kilowatts.

This is a fair indication of the conditions which will exist in the proposed system, the load centers of which are so distributed as to limit the actual average distance of transmission to about 200 miles. The economic gain in doubling the capacity of lines which cost approximately $6,000,000, the present cost of which would be at least 30 per cent more, would more than offset the cost of all necessary changes, including the adoption of the standard frequency.

Mechanical. The type of construction used on the Big Creek line has proven entirely adequate for California conditions. There have been only three mechanical failures all of which occurred shortly after the line went into service and were all due to defective line hardware. In one case the failure was due to faulty design. This fault was entirely corrected by redesigning the cable clamp so as to grip the steel core independently of the aluminum conductor. The other two were due to individual defects in parts. There have been no tower failures and no tower maintenance whatever has been required. Approximately 20 per cent of the Big Creek line is subject to ice and snow conditions, parts of it reaching altitudes of 5000 feet. Similar conditions exist over practically the entire proposed 220,000-volt system.

Operation. The most interesting feature of the operation of the Big Creek system is its reliability, which has been equal to that of steam plants of similar capacity located near load centers. Flashovers have caused only momentary interruptions and have in no case resulted in damage such as to prevent immediate resumption of service. During the greater part of the time the power has been carried over a single line for a large part of the distance.

The operating history of the Big Creek system discloses no evidence of any trouble due to the high voltage of the system, and in addition has demonstrated that higher voltages may be used with equal or greater reliability. The Big Creek 17,500 kv-a. generators have operated at 60 cycles satisfactorily and delivered full output at this frequency.

High-tension line switching and synchronizing has been carried on consistently throughout the operation of the Big Creek system without trouble, and should be possible on the 220,000-volt system. During times of switching, slight discharges, never followed by any energy current, occur on the arresters. Operating at corona voltage rather than at 80 per cent of the critical voltage it may be possible to absorb these disturbances without arresters.

Complete parallel operation of all lines must be adhered to in the proposed system. Satisfactory protective relay systems for dropping defective sections with little disturbance have been developed for present parallel transmission lines and there appear to be no obstacles to extending these to the higher voltages.

Generators. Curves of Figs. 3 and 4 show generator and line characteristics for 60-cycle, 220,000-volt systems. The full lines are the charging currents in amperes for different lengths of line plotted against per cent normal voltage. The broken lines are generator characteristics of various sizes of generators when connected to condensive loads with no field excitation. The point of intersection of the generator curves with the line charging current curve for any particular length of line determines the voltage to which the generator will build up when connected to that length of line with no field excitation. Fig. 3 is for generators with a short circuit ratio of 1.0, while Fig. 4 is for those with a ratio of 1.5.

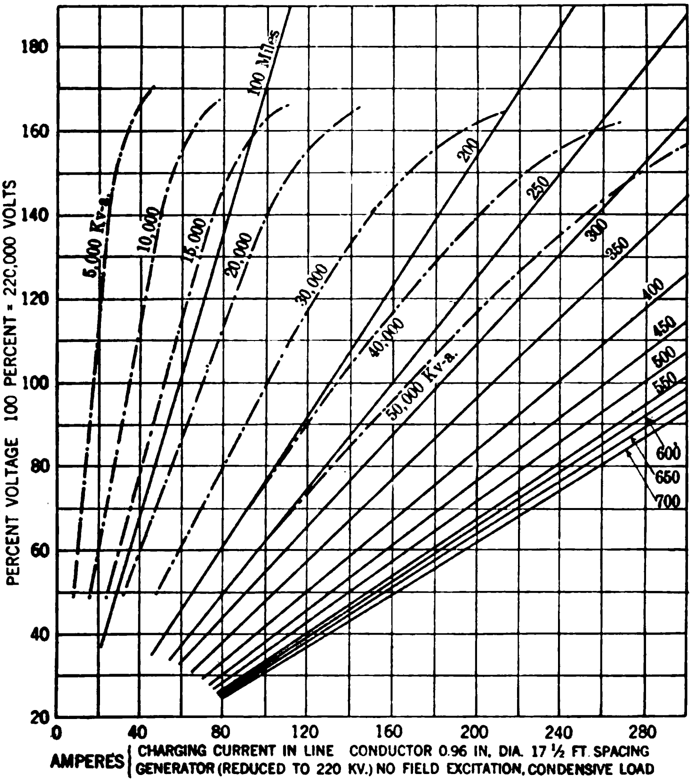

Fig. 3—Generator and Line Characteristics—60 Cycles—220,000-Volts—Generators with Short Circuit Ratio 1.0

Fig. 3 shows that with 50,000 kv-a. of generating capacity connected to a line of 250 miles, the line can be charged without losing control of the voltage with generators of this design. By having synchronous condensers connected to the line at the receiving station generators of this capacity will bring up any length of line necessary to the successful operation of the proposed system. These curves show that generators for such a system should be designed with the highest short circuit ratio that other conditions will permit in order to reduce to a minimum the tendency to become self exciting.

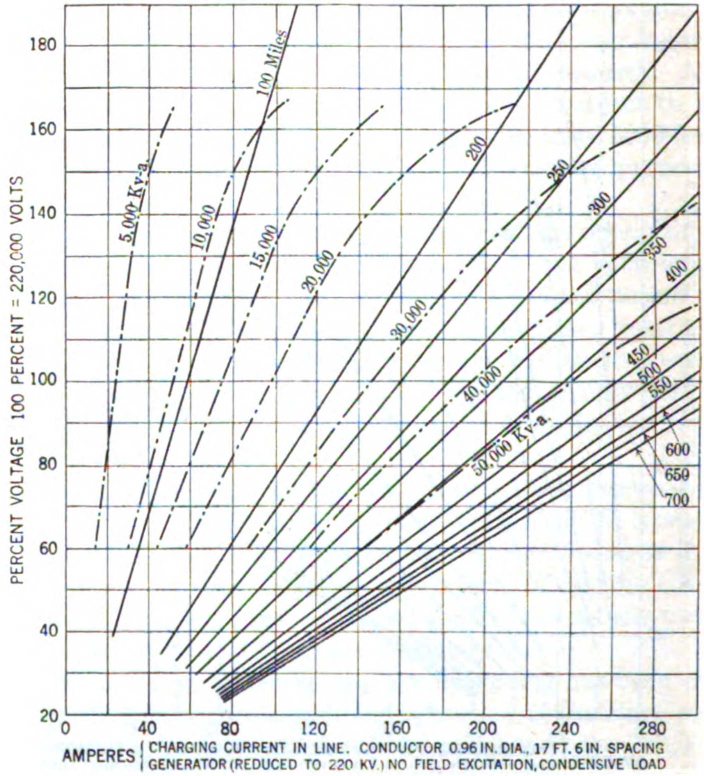

FIG. 4—GENERATOR AND LINE CHARACTERISTICS—60 CYCLES—220,000 VOLTS—GENERATORS WITH SHORT CIRCUIT RATIO 1.5

*Data for these curves were worked out in the laboratory of Throop College of Technology in 1915 and results verified by actual tests on the 17,500 kv-a. generators at Big Creek.

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*For further data and explanation of generator performance with large condensive loads see Newbury, *Electric Journal*, 1918.

Conclusions. Such a system as proposed is needed immediately; all engineering fundamentals essential to a solution of its problems are well understood and the Big Creek system

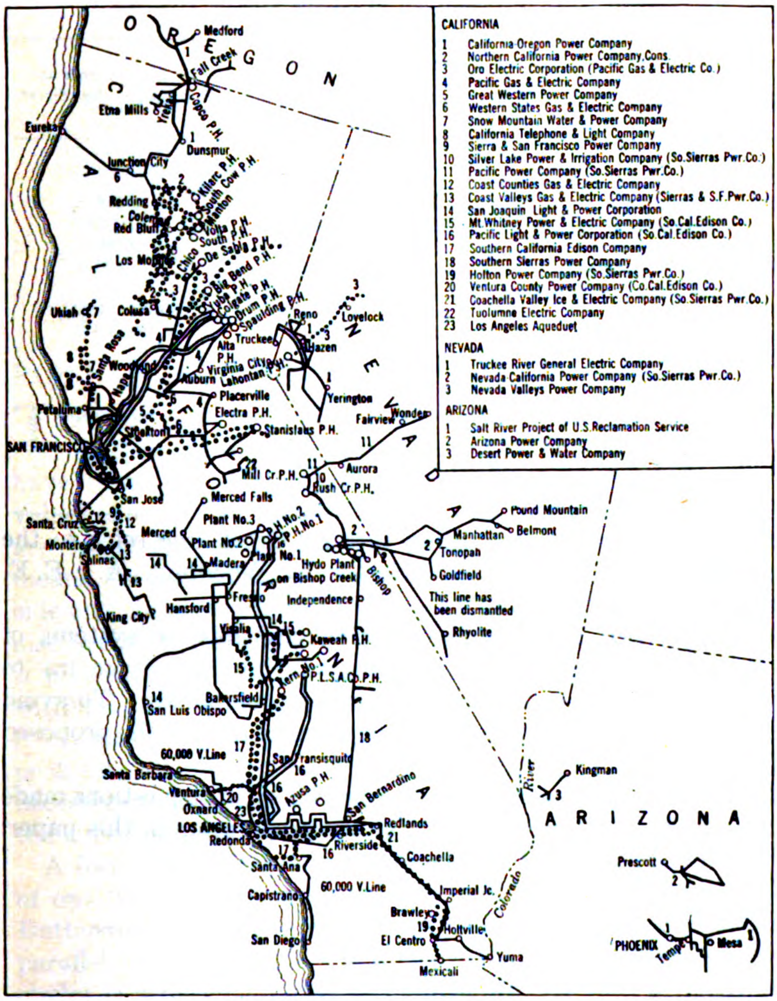
CALIFORNIA
1 California-Oregon Power Company
2 Northern California Power Company, Cons.
3 Oro Electric Corporation (Pacific Gas & Electric Co.)
4 Pacific Gas & Electric Company
5 Great Western Power Company
6 Western States Gas & Electric Company
7 Snow Mountain Water & Power Company
8 California Telephone & Light Company
9 Sierra & San Francisco Power Company
10 Silver Lake Power & Irrigation Company (So. Sierras Pwr. Co.)
11 Pacific Power Company (So. Sierras Pwr. Co.)
12 Coast Counties Gas & Electric Company
13 Coast Valleys Gas & Electric Company (Sierras & S.F. Pwr. Co.)
14 San Joaquin Light & Power Corporation
15 Mt. Whitney Power & Electric Company (So. Cal. Edison Co.)
16 Pacific Light & Power Corporation (So. Cal. Edison Co.)
17 Southern California Edison Company
18 Southern Sierras Power Company
19 Holton Power Company (So. Sierras Pwr. Co.)
20 Ventura County Power Company (Co. Cal. Edison Co.)
21 Coachella Valley Ice & Electric Company (So. Sierras Pwr. Co.)
22 Tuolumne Electric Company
23 Los Angeles Aqueduct
NEVADA
1 Truckee River General Electric Company
2 Nevada-California Power Company (So. Sierras Pwr. Co.)
3 Nevada Valleys Power Company
ARIZONA
1 Salt River Project of U.S. Reclamation Service
2 Arizona Power Company
3 Desert Power & Water Company
OREGON
CALIFORNIA
NEVADA
ARIZONA
Medford
Fall Creek
Etna Mills
Yreka
Copco P.H.
Eureka
Dunsmuir
Junction City
Redding
Kilarc P.H.
South Cow P.H.
Manton
Coleman
Red Bluff
Volta P.H.
South P.H.
De Sabla P.H.
Los Molinos
Chico
Big Bend P.H.
Yuba P.H.
Colgate P.H.
Drum P.H.
Spaulding P.H.
Ukiah
Colusa
Reno
Lovelock
Truckee
Hazen
Alta P.H.
Virginia City
Lahontan P.H.
Santa Rosa
Woodland
Napa
Auburn
Yerington
Petaluma
Placerville
Electra P.H.
Fairview
Wonder
SAN FRANCISCO
Stockton
Stanislaus P.H.
Mill Cr. P.H.
Aurora
Rush Cr. P.H.
San Jose
Merced Falls
Santa Cruz
Monterey
Salinas
Merced
Plant No. 3
Plant No. 2
Plant No. 1
P.H. No. 2
P.H. No. 1
Madera
Hydo Plant on Bishop Creek
Bishop
Pound Mountain
Manhattan
Belmont
Tonopah
Goldfield
This line has been dismantled
Rhyolite
Fresno
Independence
Hansford
King City
Visalia
Kaweah P.H.
Kern No. 1
P.L.S.A.Co. P.H.
San Luis Obispo
Bakersfield
60,000 V. Line
Santa Barbara
San Francisquito
Ventura
Oxnard
Azusa P.H.
San Bernardino
LOS ANGELES
Redondo
Redlands
Riverside
Coachella
Santa Ana
Capistrano
Imperial Jc.
Brawley
Holtville
El Centro
Yuma
Mexicali
San Diego
Colorado
River
Kingman
Prescott
PHOENIX
Tempe
Mesa

FIG. 5—MAP OF WESTERN TRANSMISSION LINES

can be used as a part of the project without material reconstruction.

To supply this need, arrangements should be made without delay for a complete working out of all details of the proposed system, as otherwise in the future it may be necessary to do a large amount of reconstruction to bring together individually-designed systems, which is never a wholly satisfactory procedure.

COMPARATIVE DATA

	Big Creek lines at 150 kv.	220 kv. lines as proposed by Silver
Aluminum steel cable		
Diameter	0.95 in.	1.036 in.
Circular mils	683,000	808,900
Weight per foot	0.75 lb.	0.94 lb.
Length of average span	750 ft.	800 ft.
Weight of towers without footings		
Suspension	4300 lb.	9000 to 14,000 lbs.
Anchor	6450 lb.	24,000 lb.
Stringing tension at 80 deg. fahr.		
No ice allowance	4740 lb.	
Ice allowance	3130 lb.	
Maximum tension allowed	8500 lb.	17,300 lb.
Insulator strings to carry load		
Suspension	1	2 and 3
Anchor	2	6

For further data regarding the Big Creek line refer to the paper 150,000 *Transmission System* by Woodbury, A. I. E. E. TRANS., 1914.

Map. Fig. 5 shows the existing transmission systems of California, Nevada, and Arizona, varying in voltage up to 150,000 and the names of the operating companies. To avoid confusion these lines are not shown on the map of the proposed system.

The authors wish to express appreciation of suggestions made by Mr. H. A. Barre which led to the preparation of this paper.

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(Subject to final revision for the Transactions.)

SOME NEW FORMULAS FOR REACTANCE COILS

BY H. B. DWIGHT

Abstract of Paper

Formulas are presented and derived, which have not been previously published, for mutual inductance of coils with parallel axes, repulsion of coils with parallel axes, and self-inductance of long cylindrical coils.

These formulas apply to practically all cases of reactance coils in common use. They are very convergent and accurate, and will give results to a given degree of accuracy with a minimum amount of labor.

For many engineering problems, precise accuracy is not required, and sets of curves are given from which approximate readings may be taken.

Part I—Mutual Inductance of Coils with Parallel Axes

THE common method of mounting reactance coils is with parallel axes, that is, side by side, and it is desirable to have formulas which apply to coils in this position. The values of mutual inductance derived in the following paragraphs are useful for calculating the unbalance in voltage and the means for correcting it, when three coils are placed side by side and connected in a three-phase circuit. The formulas are also useful in the design of radio apparatus. The calculation is very exact for widely separated coils, and it has an accuracy within a small percentage for coils placed as close together as it is usual to mount reactance coils. For usual engineering problems where precise accuracy is not required, it is not necessary to calculate the results, but values may be read from the curves of Fig. 1, thus saving the labor of computation.

A formula for the mutual inductance of two circles formed of one turn of infinitesimally thin wire has been given by S. Butterworth,* for the case when the axes of the circles are parallel, and when the distance between the centers of the circles is somewhat larger than their diameters. In order to obtain a formula suitable for commercial reactance coils of many turns, the author has integrated the above formula four

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Manuscript of this paper was received February 17, 1919.

*Scientific Paper No. 320 of the Bureau of Standards, Washington, D. C., June, 1918, Eq. 10 A, and *Philosophical Magazine*, Vol. 31, 1916, page 443.

times over the rectangular section of a cylindrical coil, with the following result:—

M, in henrys,

$$= \frac{2\,\pi^2\,a^3\,N^2}{0.3937\,b^2\,10^9}\left[\frac{a}{r}\left(\frac{r}{s}-1\right)\left(1+\frac{c^2}{6\,a^2}+\frac{c^4}{144\,a^4}\right)\right.$$

$$+\frac{a^3}{2\,r^3}\left(1-\frac{3}{2}\,\frac{s^2}{r^2}+\frac{r^3}{2\,s^3}\right)$$

$$\left(1+\frac{7}{12}\,\frac{c^2}{a^2}+\frac{13}{240}\,\frac{c^4}{a^4}+\frac{c^6}{960\,a^6}\right)$$

$$-\frac{5}{8}\,\frac{a^5}{r^5}\left(1-\frac{5\,s^2}{r^2}+\frac{35}{8}\,\frac{s^4}{r^4}-\frac{3}{8}\,\frac{r^5}{s^5}\right)$$

$$\left(1+\frac{17}{15}\,\frac{c^2}{a^2}+\frac{169}{600}\,\frac{c^4}{a^4}+\frac{41}{2800}\,\frac{c^6}{a^6}+\frac{113}{672{,}000}\,\frac{c^8}{a^8}\right)$$

$$+\frac{35}{32}\,\frac{a^7}{r^7}\left(1-\frac{21}{2}\,\frac{s^2}{r^2}+\frac{189}{8}\,\frac{s^4}{r^4}-\frac{231}{16}\,\frac{s^6}{r^6}+\frac{5}{16}\,\frac{r^7}{s^7}\right)$$

$$\left(1+\frac{155}{84}\,\frac{c^2}{a^2}+\frac{2167}{2520}\,\frac{c^4}{a^4}+\frac{541}{4704}\,\frac{c^6}{a^6}\right.$$

$$\left.\left.+\frac{2129}{3136\times 180}\,\frac{c^8}{a^8}+\frac{197}{1960\times 3456}\,\frac{c^{10}}{a^{10}}\right)+\text{etc.}\right] \qquad (\mathbf{1})$$

where $r^2 = s^2 + b^2$ and $a = \frac{1}{2}\,d$ = the mean radius of the coil. N is the number of turns in each coil.

The dimensions are assumed to be given in inches; if they are given in centimeters, the factor 0.3937 should be omitted. In measuring the coil, each dimension should be taken as the number of wires or cables in that dimension times their pitch. The actual measured dimension over the copper should not be used, as it is slightly too small.

It will be noted that formula (**1**) is indeterminate when $b = 0$ and therefore $r = s$. For such a case, the following formula should be used:

$$M = \frac{\pi^2\,a^4\,N^2}{0.3937\,s^3\,10^9}\left[\left(1+\frac{c^2}{6\,a^2}+\frac{c^4}{144a^4}\right)\right.$$

$$+\frac{9}{4}\,\frac{a^2}{s^2}\left(1+\frac{7}{12}\,\frac{c^2}{a^2}+\frac{13}{240}\,\frac{c^4}{a^4}+\frac{c^6}{960\,a^6}\right)$$

$$+\frac{375}{64}\frac{a^4}{s^4}\left(1+\frac{17}{15}\frac{c^2}{a^2}+\frac{169}{600}\frac{c^4}{a^4}+\frac{41}{2800}\frac{c^6}{a^6}+\frac{113}{672{,}000}\frac{c^8}{a^8}\right)$$

$$+\frac{8575}{512}\frac{a^6}{s^6}\left(1+\frac{155}{84}\frac{c^2}{a^2}+\frac{2167}{2520}\frac{c^4}{a^4}+\frac{541}{4704}\frac{c^6}{a^6}+\frac{2129}{3136\times 180}\frac{c^8}{a^8}+\frac{197}{1960\times 3456}\frac{c^{10}}{a^{10}}\right)+\text{etc.}\Bigg] \quad (\mathbf{2})$$

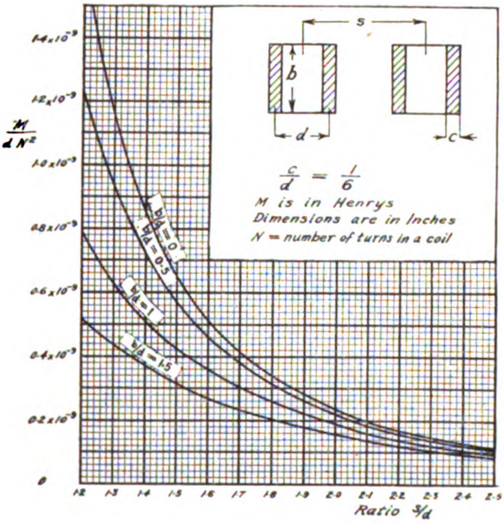

Fig. 1—Mutual Inductance of Reactance Coils with Parallel Axes

This gives the mutual inductance of two flat disks in the same plane.

An approximate formula for the mutual inductance of two reactance coils with parallel axes has been previously published by the writer.* This was derived by making a certain distortion of one of the coils which, as was stated, tended to make the result slightly too small. The results of this formula for one shape of coil are shown in Curve II, Fig. 2. In order to show that the results were accurate enough for engineering

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*"Repulsion and Mutual Inductance of Reactors", by H. B. Dwight, *The Electrical World*, p. 1148, June 16, 1917.

work, another formula was derived using a greater distortion which tended to make the results distinctly too large, as shown in Curve III. It is interesting to note that Curve I, which shows the result of the formula now given, lies just a little above Curve II.

The new formula is more convenient to use than the older approximate formula, and gives more accurate results for any given position of the coils. Neither formula is very convergent for s/d less than about 1.2.

The case outlined in Fig. 1, in which the two coils with parallel axes are alike and stand on the same plane, is the simplest for calculation. However, if the coils have parallel axes and are alike, and one stands on a plane a distance e higher than the other, the formula for their mutual inductance is not very complicated. It is as follows:

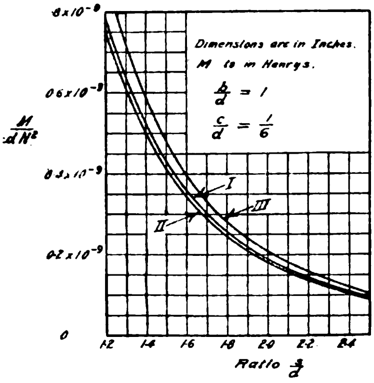

FIG. 2—COMPARISON WITH APPROXIMATE CURVES

M, in henrys,

$$= \frac{\pi^2 N^2}{0.3937\, b^2 \times 10^9} \Bigg[a^4 \left(\frac{1}{p} - \frac{2}{q} + \frac{1}{r} \right)$$

$$\left(1 + \frac{c^2}{6\, a^2} + \frac{c^4}{144\, a^4} \right) - \frac{1}{2}\, a^6 \left\{ \left(\frac{1}{p^3} - \frac{2}{q^3} + \frac{1}{r^3} \right) \right.$$

$$\left. - \frac{3\, s^2}{2} \left(\frac{1}{p^5} - \frac{2}{q^5} + \frac{1}{r^5} \right) \right\}$$

$$\left(1 + \frac{7}{12} \frac{c^2}{a^2} + \frac{13}{240} \frac{c^4}{a^4} + \frac{c^6}{960\, a^6} \right)$$

$$+\frac{5}{8}a^8\left\{\left(\frac{1}{p^5}-\frac{2}{q^5}+\frac{1}{r^5}\right)-5\,s^2\left(\frac{1}{p^7}-\frac{2}{q^7}+\frac{1}{r^7}\right)\right.$$

$$\left.+\frac{35\,s^4}{8}\left(\frac{1}{p^9}-\frac{2}{q^9}+\frac{1}{r^9}\right)\right\}$$

$$\left(1+\frac{17}{15}\,\frac{c^2}{a^2}+\frac{169}{600}\,\frac{c^4}{a^4}+\frac{41}{2800}\,\frac{c^6}{a^6}+\frac{113}{672{,}000}\,\frac{c^8}{a^8}\right)$$

$$-\frac{35}{32}a^{10}\left\{\left(\frac{1}{p^7}-\frac{2}{q^7}+\frac{1}{r^7}\right)-\frac{21\,s^2}{2}\left(\frac{1}{p^9}-\frac{2}{q^9}+\frac{1}{r^9}\right)\right.$$

$$+\frac{189\,s^4}{8}\left(\frac{1}{p^{11}}-\frac{2}{q^{11}}+\frac{1}{r^{11}}\right)$$

$$\left.-\frac{231\,s^6}{16}\left(\frac{1}{p^{13}}-\frac{2}{q^{13}}+\frac{1}{r^{13}}\right)\right\}$$

$$\left(1+\frac{155}{84}\,\frac{c^2}{a^2}+\frac{2167}{2520}\,\frac{c^4}{a^4}+\frac{541}{4704}\,\frac{c^6}{a^6}+\frac{2129}{3136\times 180}\,\frac{c^8}{a^8}\right.$$

$$\left.+\frac{197}{1960\times 3456}\,\frac{c^{10}}{a^{10}}\right)+\text{etc.}\Bigg] \qquad (3)$$

where $p^2 = s^2 + (b-e)^2$

$q^2 = s^2 + e^2$

and $r^2 = s^2 + (b+e)^2$

This formula includes the case of two coaxial coils, when the coils are not near to each other. When the coils are coaxial, the mutual inductance is opposite in sign to the value when the coils are side by side. There is a position, when two coils with parallel axes are diagonally from each other, for which the mutual inductance is zero.

The formula for the mutual inductance of two unequal coils with parallel axes, in any relative position, is similar to the above, but is, of course, more complicated.

Example I. Find the voltage drop due to mutual inductance in each of three coils placed side by side in a row, and carrying three-phase, 60-cycle current, 400 amperes per phase, the data being as follows:—

Mean radius of coils $= a =$ 12.76 inches.
Length of coils $= b =$ 30.87 "
Thickness of winding $= c =$ 4.87 "
Number of turns $= N =$ 114
Distance between centers = 45 inches.

Let the three coils in a row be called A, B and C. For A and B, $s = 45$ inches.

$$M_{AB} = 0.00142\,(0.0508 + 0.0061 + 0.0007 + 0.00008)$$
$$= 8.2 \times 10^{-5} \text{ henry.}$$

or using Fig. 1, $\dfrac{s}{d} = \dfrac{45}{25.52} = 1.76$

and $\dfrac{b}{d} = \dfrac{30.87}{25.52} = 1.21$

$$M_{AB} = 0.25 \times 10^{-9} \times 114^2 \times 25.52 = 8.3 \times 10^{-5} \text{ henry.}$$

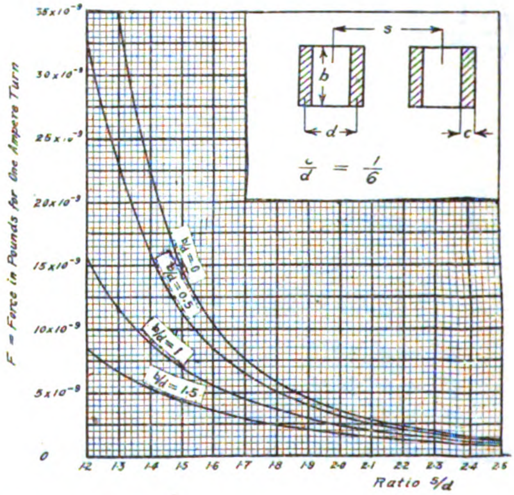

Fig. 3—Mechanical Force Between Reactance Coils with Parallel Axes

Average force in pounds = F (from curves) $I_1 I_2 N^2 \cos\theta$ where N is the number of turns in each coil and where θ is the phase angle between I_1 and I_2 which are in amperes.

Using a spacing $s = 90$ inches

$$M_{AC} = 1.1 \times 10^{-5} \text{ henry.}$$

Let the currents in the three coils A, B and C, which are 120 deg. apart in phase, be

$$I_A = 400 \text{ amperes}$$
$$I_B = -200 + j\,200\sqrt{3} \text{ amperes}$$
and
$$I_C = -200 - j\,200\sqrt{3} \text{ amperes}$$

The drop in A due to mutual inductance is

$$2\pi \times 60j\,(I_B M_{AB} + I_C M_{AC}) = -9.3 - j\,7.0 \text{ volts.}$$

The drop in B due to mutual inductance is

$2\,\pi \times 60\,j\,(I_A\,M_{AB} + I_C\,M_{BC}) = 10.7 + j\,6.2$ volts.

The drop in C due to mutual inductance is

$2\,\pi \times 60\,j\,(I_A\,M_{AC} + I_B\,M_{BC}) = 10.7 - j\,4.5$ volts.

PART II—REPULSION OF COILS WITH PARALLEL AXES

The formula for calculating the mechanical force exerted between reactance coils placed in the usual way, side by side with parallel axes, may be derived by differentiating the expression for the mutual inductance of the coils in the same position. Curves are given in Fig. 3 which should be more convenient in most cases than the formula, for solving problems.

The differential with respect to s of formula (**1**) for mutual inductance, using absolute units, is equal to the mechanical force in dynes between the coils when one absampere is flowing in each coil, the currents being in phase. Changing the units, this gives the force in pounds for one ampere turn, which is equal to:

$$= \frac{2\,\pi^2\,a^2}{4.45 \times 10^7\,b^2}\left[\frac{a^2}{r^2}\left(\frac{r^2}{s^2} - \frac{s}{r}\right)\left(1 + \frac{c^2}{6\,a^2} + \frac{c^4}{144\,a^4}\right)\right.$$

$$+ \frac{3}{4}\,\frac{a^4}{r^4}\left(\frac{4\,s}{r} - \frac{5\,s^3}{r^3} + \frac{r^4}{s^4}\right)$$

$$\left(1 + \frac{7}{12}\,\frac{c^2}{a^2} + \frac{13}{240}\,\frac{c^4}{a^4} + \frac{c^6}{960\,a^6}\right)$$

$$- \frac{75}{64}\,\frac{a^6}{r^6}\left(\frac{8\,s}{r} - \frac{28\,s^3}{r^3} + \frac{21\,s^5}{r^5} - \frac{r^6}{s^6}\right)$$

$$\left(1 + \frac{17}{15}\,\frac{c^2}{a^2} + \frac{169}{600}\,\frac{c^4}{a^4} + \frac{41}{2800}\,\frac{c^6}{a^6} + \frac{113}{672{,}000}\,\frac{c^8}{a^8}\right)$$

$$+ \frac{245}{256}\,\frac{a^8}{r^8}\left(\frac{32\,s}{r} - \frac{216\,s^3}{r^3} + \frac{396\,s^5}{r^5} - \frac{429}{2}\,\frac{s^7}{r^7} + \frac{5}{2}\,\frac{r^8}{s^8}\right)$$

$$\left(1 + \frac{155}{84}\,\frac{c^2}{a^2} + \frac{2167}{2520}\,\frac{c^4}{a^4} + \frac{541}{4704}\,\frac{c^6}{a^6} + \frac{2129}{3136 \times 180}\,\frac{c^8}{a^8}\right.$$

$$\left.\left. + \frac{197}{1960 \times 3456}\,\frac{c^{10}}{a^{10}}\right) + \text{etc.}\right] \qquad (\mathbf{4})$$

where $r^2 = s^2 + b^2$ and $a = \frac{1}{2}d$ = the mean radius of the coil. The dimensions may be given in either inches or centimeters, since only ratios of dimensions appear.

It results therefore, that if all the dimensions, including spacing, of a group of coils be increased by a certain ratio, but the currents be left the same, the mechanical force in pounds is not changed at all. However, large coils are generally subject to large forces, since they carry proportionately large currents.

When different alternating currents I_1 and I_2, at a phase angle θ, flow in the two coils, the average force in pounds is

$$F\, I_1\, I_2\, N^2 \cos\theta$$

where I_1 and I_2 are the effective values of the currents in amperes and where N is the number of turns in each coil.

As in the case of the expression for mutual inductance, formula (**4**) becomes indeterminate when $b = 0$ and therefore $r = s$. In such a case, which is that of two flat disks in the same plane, the following formula may be used:

$$\begin{aligned} F, \text{ in pounds, } = \frac{3\,\pi^2 a^4}{4.45 \times 10^7 s^4} \bigg[& \left(1 + \frac{c^2}{6\,a^2} + \frac{c^4}{144\,a^4}\right) \\ & + \frac{15}{4}\frac{a^2}{s^2}\left(1 + \frac{7}{12}\frac{c^2}{a^2} + \frac{13}{240}\frac{c^4}{a^4} + \frac{c^6}{960\,a^6}\right) \\ & + \frac{875}{64}\frac{a^4}{s^4}\bigg(1 + \frac{17}{15}\frac{c^2}{a^2} + \frac{169}{600}\frac{c^4}{a^4} + \frac{41}{2800}\frac{c^6}{a^6} \\ & \qquad + \frac{113}{672{,}000}\frac{c^8}{a^8}\bigg) \\ & + \frac{25{,}725}{512}\frac{a^6}{s^6}\bigg(1 + \frac{155}{84}\frac{c^2}{a^2} + \frac{2167}{2520}\frac{c^4}{a^4} + \frac{541}{4704}\frac{c^6}{a^6} \\ & \qquad + \frac{2129}{3136 \times 180}\frac{c^8}{a^8} + \frac{197}{1960 \times 3456}\frac{c^{10}}{a^{10}}\bigg) + \text{etc.}\bigg] \end{aligned} \tag{5}$$

The mechanical force between two coils side by side with parallel axes is a repulsion when the currents flow in the same direction around both coils, and it is an attraction when the currents are in opposite directions.

The value of force as calculated above is the average force, that is, the effective steady sustained pressure, due to alternating current. It is the same in value as the force due to direct current. At the peak of the alternating-current wave, when the currents are in phase, the force rises to double the above value, and it becomes zero when the momentary current becomes zero.

A comparison is shown in Fig. 4 between calculated values and a test curve.* The approximate data for the test curve are given in example II.

The approximate formula previously published by the author in the *Electrical World* of June 16, 1917, gives results which are slightly less than those of formula (**4**) which are more accurate. The curves have practically the same relative position as in Fig. 2.

Example II—Find the average mechanical force acting on each of two coils carrying single-phase currents which are in phase, the conditions being as follows:

Mean radius of coils $= a = 12.76$ inches.
Length of coils $= b = 30.87$ "
Thickness of winding $= c = 4.87$ "
Number of turns $= N = 114$
Current in amperes $= I_1 = I_2 = 400$ amperes.

The coils are placed side by side, with the parallel axes 45 inches apart.

$$\text{Force} = 158\,(0.0362 + 0.0065 + 0.0010 + 0.0001) = 6.89 \text{ pounds.}$$

Using the curves of Fig. 3,

$$\frac{b}{d} = \frac{30.87}{25.52} = 1.21, \text{ and } \frac{s}{d} = \frac{45}{25.52} = 1.76$$

$$\text{Force} = 3.3 \times 10^{-9} \times 400^2 \times 114^2 = 6.8 \text{ pounds.}$$

Example III. Find the average mechanical force on each of three coils of the same size and spacing as those in Example II, placed side by side in a row, and carrying three-phase current, 400 amperes per phase. In determining the average mechanical forces due to three-phase currents, the forces due to the products of the instantaneous values of two alternating currents, which are 120 deg. out of phase, are calculated in the same way as the watts due to the products of the instantaneous values of

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*The test curve was published in an article on "The Mechanical Stresses in Reactance Coils" by W. M. Dann, *The Electric Journal*, page 206, April 1914.

an alternating current and an alternating voltage which are out of phase.

Let the three coils in a row be called A, B, and C. The currents in them are 120 deg. apart, in phase. The average force on A caused by I_B is

$$6.89 \cos 120 \text{ deg.} = 3.44 \text{ pounds,}$$

the calculation being similar to Example II.

To find the force on A caused by I_c, formula (**4**) is used, the axial spacing being 90 in. The average force on A caused by I_c is

$$0.50 \cos 120 \text{ deg.} = 0.25 \text{ pounds.}$$

This is to be added to the force caused by I_B, making a total average force on A of 3.69 pounds, tending to move it toward the center coil. Coil C is also under an average attraction of 3.69 pounds. Coil B is attracted by both A and C, and although there is a momentary force first in one direction and then in the other, the average force on B is zero.

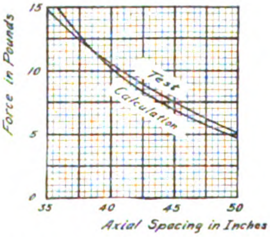

FIG. 4—COMPARISON OF CALCULATION WTIH TEST

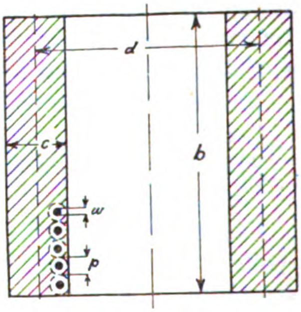

FIG. 5—SECTION OF REACTANCE COIL

Since the above forces increase as the square of the current they attain large values at times of short circuit.

PART III—SELF-INDUCTANCE OF LONG REACTANCE COILS

Reactance coils, as generally manufactured, are cylindrical in shape and have an axial length practically as long as, or longer than, their mean diameter. The radial thickness of the winding is usually considerable. The self-inductance of a thick coil with usual radial thickness of winding, may be as much as 15 per cent less than the self-inductance, L_s, of a very thin solenoid of the same mean diameter. The self-inductance of the above described thick coils may be calculated very precisely by formula (**13**) given below, which may be used to a fair degree of approximation for coils somewhat shorter than their mean diameter. Curves are given in Figs. 6 and 7 from which readings may be taken which will be correct within about one per cent for most shapes of reactance coils.

An alternative method for determining the self-inductance of a cylindrical coil is to obtain the value of L_s from Table XXI, Scientific Paper No. 169 of the Bureau of Standards, and obtain the correction for the thickness of the coils from Dr. E. B. Rosa's equations (91) and (93) and Tables IX and X of the same paper. This method is especially useful for coils just shorter than their mean diameter, since other formulas are then not very convergent.

As indicated in Fig. 5, all the dimensions of a coil should be measured to the pitch lines of the conductors. Thus the length of the coil should be taken as the number of conductors per layer multiplied by the pitch of the conductors. The exact dimensions over the copper are slightly too small and should not be used.

In order to obtain an expression for the self-inductance of a thick cylindrical coil, it is first necessary to know the mutual inductance of two coaxial and concentric thin solenoids of equal length. For long solenoids this has been given in a useful form by T. H. Havelock.*

By using the form in elliptic integrals given in equation (**4**) of Havelock's paper in the *Philosophical Magazine*, and by changing to the dimensions shown in Fig. **5**, the expression for mutual inductance becomes:

$$M = \frac{\pi^2 d^2 N^2}{b^2} \Bigg[b - \frac{2\,D}{3\,\pi\,d^2} \left\{ (D^2 + d^2)\,E - (D^2 - d^2)\,F \right\}$$

$$- D \left\{ - \frac{1}{8}\,\frac{D}{b} + \frac{1}{128}\left(1 + \frac{d^2}{D^2}\right)\frac{D^3}{b^3} \right.$$

$$- \frac{1}{1024}\left(1 + 3\,\frac{d^2}{D^2} + \frac{d^4}{D^4}\right)\frac{D^5}{b^5}$$

$$\left. + \frac{5}{2^{15}}\left(1 + 6\,\frac{d^2}{D^2} + 6\,\frac{d^4}{D^4} + \frac{d^6}{D^6}\right)\frac{D^7}{b^7} - \dots \right\} \Bigg]$$

abhenrys. (**6**)

---

*The *Philosophical Magazine*, March 1908, Page 340, equation 25: and *Bulletin* of the Bureau of Standards, Vol. 8, No. 1, 1911, Page 56 equation 38.

where d and D are the diameters of the two thin solenoids, where N is the number of turns on each solenoid, and where F and E are complete elliptic integrals of the first and second kinds, to modulus d/D.

The two elliptic integrals can be expanded in terms of the complementary modulus k' as follows:[*]

$$E = 1 + \frac{1}{2} k'^2 \left(\text{logh} \frac{4}{k'} - \frac{1}{1.2} \right)$$

$$+ \frac{1^2\, 3}{2^2\, 4} k'^4 \left(\text{logh} \frac{4}{k'} - \frac{2}{1.2} - \frac{1}{3.4} \right) + \ldots$$

$$F = \text{logh} \frac{4}{k'} + \frac{1^2}{2^2} k'^2 \left(\text{logh} \frac{4}{k'} - \frac{2}{1.2} \right)$$

$$+ \frac{1^2\, 3^2}{2^2\, 4^2} k'^4 \left(\text{logh} \frac{4}{k'} - \frac{2}{1.2} - \frac{2}{3.4} \right) + \ldots \qquad (7)$$

where $k' = \sqrt{1 - k^2} = \sqrt{1 - d^2/D^2}$

The expression for mutual inductance can now be integrated twice over the section of the thick coil indicated in Fig. 5, and the following formula for the self-inductance of a long thick coil is obtained:

$$L = L_s + \Delta L \qquad (8)$$

where L_s, in henrys, $= \dfrac{\pi^2 d^2 N^2}{0.3937 \times 10^9\, b} \left[1 - \dfrac{4\, d}{3\, \pi\, b} \right.$

$$\left. + \frac{1}{8} \frac{d^2}{b^2} - \frac{1}{64} \frac{d^4}{b^4} + \frac{5}{1024} \frac{d^6}{b^6} - \ldots \right] \qquad (9)$$

and where ΔL, in henrys,

$$= \frac{\pi^2 d^2 N^2}{0.3937 \times 10^9\, b} \left[- \frac{2}{3} \frac{c}{d} + \frac{1}{3} \frac{c^2}{d^2} \right.$$

$$+ \frac{4\, d}{3\, \pi\, b} \left\{ \frac{1}{4} \frac{c^2}{d^2} \left(\text{logh} \frac{4\, d}{c} - \frac{23}{12} \right) - \frac{1}{80} \frac{c^4}{d^4} \right.$$

$$\left. \left(\text{logh} \frac{4\, d}{c} - \frac{1}{20} \right) + \ldots \right\}$$

---

[*] *Bulletin* of the Bureau of Standards, Vol. 8, No. 1, by E. B. Rosa and F. W. Grover, equation 3, page 8.

$$+\frac{c^2}{d^2}\left\{\frac{1}{12}\frac{d^2}{b^2}-\frac{7}{192}\frac{d^4}{b^4}+\frac{17}{768}\frac{d^6}{b^6}\right.$$

$$\left.-\frac{775}{32\times 1536}\frac{d^8}{b^8}+\ldots\right\}$$

$$+\frac{c^4}{d^4}\left\{\frac{1}{72}\frac{d^2}{b^2}-\frac{13}{960}\frac{d^4}{b^4}+\frac{169}{7680}\frac{d^6}{b^6}\right.$$

$$\left.-\frac{2167}{32\times 2304}\frac{d^8}{b^8}+\ldots\right\}+\ldots$$

$$\left.+\frac{2b}{\pi\, q\, d\, N}\left(\text{logh}\,\frac{p}{w}+0.14\right)\right] \tag{10}$$

In the above formulas, N is the number of turns of effective conductor in the coil, q is the number of wires or cables in parallel, and the dimensions are in inches. If the dimensions are in centimeters, the factor 0.3937 should be omitted, and if the inductance is to be given in abhenrys instead of henrys the factor 10^9 should be omitted. Note that

$$\begin{aligned}\text{logh}\, m &= \text{the hyperbolic or natural logarithm of } m\\ &= 2.3026 \log_{10} m.\end{aligned}$$

The quantity L_s is the self-inductance of an infinitely thin solenoid of diameter d. Formula (**9**) is the same as (79), Bulletin of the Bureau of Standards, Vol. 8, No. 1 or (21A), Scientific Paper No. 320 of the Bureau of Standards. The general term of the series may be obtained from either of these references. There are other formulas (See 11) which are more convergent than (**9**). The value of L_s may also be accurately and conveniently found from Table XXI Bulletin of the Bureau of Standards, Vol. 8, No. 1.

The quantity ΔL, given by (**10**), is the change in the inductance due to the radial thickness of the winding. Formula (**10**) should not be used for practical problems, because formula (**13**) to be given later, is more convergent, and therefore more convenient and accurate, for any coil with which (**10**) can be used. Formula (**10**) was published by the author in the *Electrical World*, Feb. 9, 1918, page 300. It gives the same result, except for the term $\frac{2167}{32\times 2304}\frac{d^8}{b^8}$, as a method published by S. Butterworth in the *Proceedings* of the Physical Society of London, Vol. 27, 1915, page 371.

It is assumed that the coil is wound with round wire or cable. The last term of (**10**) represents the effect of the air space between the wires.

A very convergent formula for the self-inductance of an infinitely thin solenoid which has not been previously published, may be derived directly from (36) or (39), Bulletin of the Bureau of Standards, Vol. 8, No. 1, by making the dimensions of the two solenoids equal, thus obtaining the self-inductance of one solenoid instead of the mutual inductance of two. Both (**36**) and (**39**) give the same result:

$$L_s\text{, in henrys, } = \frac{\pi^2 d^2 N^2}{0.3937 \times 10^9 b} \times \frac{d}{2b} \left[\frac{1}{m} - \frac{8}{3\pi} - \frac{m^3}{8} + \frac{m^5}{16} - \frac{15}{128} m^7 + \frac{21}{128} m^9 - \frac{315}{1024} m^{11} + \frac{297}{512} m^{13} - \frac{39{,}039}{32{,}768} m^{15} + \ldots \right] \qquad \textbf{(11)}$$

where $m^2 = \dfrac{d^2}{d^2 + 4b^2}$

This is much more convergent than (9). It is somewhat more convergent than (20 A), Scientific Paper No. 320 of the Bureau of Standards, since $m^2 = \dfrac{d^2}{d^2 + 4b^2}$ is smaller than $k^2 = \dfrac{d^2}{d^2 + b^2}$. When $b = d$, 9 terms of (11) give six significant figures, but 13 terms of (20 A) are required to give this result.

Formula (11) need not necessarily be used for obtaining the value of L_s, because formulas (76), (77), and (78), Bulletin of the Bureau of Standards, Vol. 8, No. 1, are extremely convergent, and very accurate values of L_s can also be easily obtained from Table XXI of the same Bulletin.

Series in m for thick coils can be derived (see formula 13) which are similar to those in d/b of formula (**10**), but which are much more convergent than they are, and which therefore supersede them for practical calculations. These series in m have not been previously published. The series in m will give

5 or 6 significant figures for the self inductance of a thick cylindrical coil whose length is as short as its diameter, but formula (**10**) is not nearly so accurate for such a short coil. That the two formulas (**10**) and (**13**) are equivalent may be shown by the fact that they give the same results for any problem for which they are both convergent. It is also proved by expanding the terms of one formula by the binomial theorem, and this is found to produce the other formula. The derivation of (**13**) is as follows.

It is first necessary to establish a proposition regarding the mutual inductance of two solenoids, similar to Maxwell's proposition regarding two coils, in paragraph 700 of "Electricity and Magnetism".* In the same manner as in the paragraph referred to, it may be shown that, if M_s is the mutual inductance of the central solenoids of two cylindrical coils of mean radii a_1 and a_2 and of thicknesses of winding c_1 and c_2, then the mutual inductance of the two thick coils is

$$\begin{aligned} M = M_s &+ \frac{c_1^2}{2^2\,\underline{|3}}\,\frac{\partial^2 M_s}{\partial a_1^2} + \frac{c_2^2}{2^2\,\underline{|3}}\,\frac{\partial^2 M_s}{\partial a_2^2} \\ &+ \frac{c_1^4}{2^4\,\underline{|5}}\,\frac{\partial^4 M_s}{\partial a_1^4} + \frac{c_1^2\,c_2^2}{2^4\,\underline{|3}\,\underline{|3}}\,\frac{\partial^4 M_s}{\partial a_1^2\,\partial a_2^2} + \frac{c_2^4}{2^4\,\underline{|5}}\,\frac{\partial^4 M_s}{\partial a_2^4} \\ &+ \frac{c_1^6}{2^6\,\underline{|7}}\,\frac{\partial^6 M_s}{\partial a_1^6} + \frac{c_1^4\,c_2^2}{2^6\,\underline{|3}\,\underline{|5}}\,\frac{\partial^6 M_s}{\partial a_1^4\,\partial a_2^2} \\ &+ \frac{c_1^2\,c_2^4}{2^6\,\underline{|3}\,\underline{|5}}\,\frac{\partial^6 M_s}{\partial a_1^2\,\partial a_2^4} + \frac{c_2^6}{2^6\,\underline{|7}}\,\frac{\partial^6 M_s}{\partial a_2^6} + \cdots \end{aligned} \qquad (\mathbf{12})$$

This formula is most accurate for coils that are far apart, and it does not give good results for coils that are close together. It may be useful for giving extensions to present formulas for mutual inductance of solenoids.

If formula (17), Bulletin of the Bureau of Standards Vol. 8, No. 1, for the mutual inductance of two circles far apart, be integrated to give the mutual inductance of two coaxial solenoids whose centers are far apart measured along the axis, terms are obtained which are of the same form as the second half of formula (38) of the above bulletin, which forms a series in A/l. See formula (3) when $s = 0$. Now proposition (**12**) gives exactly the effect of the thicknesses c_1 and c_2 of the coils for the formula for coils far apart, and it is to be expected that it will give the effect of c_1 and c_2 for the same terms which appear in the last half of (38, Bulletin, Vol. 8, No. 1).

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*See also Scientific Paper No. 169 of the Bureau of Standards by E. B. Rosa and F. W. Grover, page 33.

This is found to be the case, and the series in c^2 and c^4 in the last half of (**10**), can be derived by means of (**12**). The latter method is much easier than the method of straight integration of (38, Bulletin Vol. 8, No. 1), since differentiation is in general a simpler process than integration, and fewer and smaller terms are required to be handled.

Now it is noticeable that formula (36) of the Bulletin, Vol. 8, No. 1, contains the first line of (38) of the same bulletin. Therefore the terms in A/r of (36, Vol. 8, No. 1), give the same total result as the terms in A/l of (38, Vol. 8, No. 1). This may be proved definitely by expanding one set of terms by the binomial theorem, and they are found to produce the other set. Therefore, since proposition (**12**) applies to the terms in A/l of (38 Vol. 8, No. 1), it applies to the terms in A/r of (36, Vol. 8, No. 1). A similar statement applies to (39, Vol. 8, No. 1) since that formula is the same as (36, Vol. 8, No. 1) when the two solenoids are of equal length.

The differentiation of (36) or (39) (Vol. 8, No. 1), is not difficult, and then proposition (**12**) can be applied. It is found by expanding some of the terms by the binomial theorem that when $A = a$

$$\frac{\partial^2 M}{\partial A^2} = \frac{\partial^2 M}{\partial a^2}$$

as would be expected, and this produces a certain simplification in the series. Terms from formula (**10**) extended are then included to give the effect of integrating the terms in a/A of (36) or (38) (Vol. 8, No. 1), and the following complete result is obtained:

10.5

$$\Delta L, \text{ in henrys} = \frac{\pi^2 d^2 N^2}{0.3937 \times 10^9 b} \Bigl[-\frac{2}{3}\frac{c}{d} + \frac{1}{3}\frac{c^2}{d^2}$$

$$+ \frac{4d}{3\pi b} \Bigl\{ \frac{1}{4}\frac{c^2}{d^2}\left(\text{logh}\,\frac{4d}{c} - \frac{23}{12}\right) - \frac{1}{80}\frac{c^4}{d^4}$$

$$\left(\operatorname{logh}\frac{4\,d}{c}-\frac{1}{20}\right)-\frac{1}{896}\,\frac{c^6}{d^6}\left(\frac{23}{20}\operatorname{logh}\frac{4\,d}{c}-\frac{4547}{5600}\right)$$

$$\left.+\ldots\right\}$$

$$+\frac{c^2}{d^2}\times\frac{d}{b}\left\{\frac{m}{6}-\frac{5}{24}m^3+\frac{m^5}{3}-\frac{95}{128}m^7+\frac{217}{128}m^9\right.$$

$$-\frac{2135}{512}m^{11}+\frac{11\times1961}{2048}m^{13}-\frac{13\times68{,}915}{32{,}768}m^{15}$$

$$\left.+\ldots\right\}$$

$$+\frac{c^4}{d^4}\times\frac{d}{b}\left\{\frac{m}{36}-\frac{17}{180}m^3+\frac{53}{96}m^5-\frac{1265}{576}\right.$$

$$m^7+\frac{38{,}857}{4608}m^9-\frac{3913}{128}m^{11}+\frac{231\times9551}{20{,}480}m^{13}$$

$$\left.-\frac{143\times10{,}625}{4096}m^{15}+\ldots\right\}$$

$$+\frac{c^6}{d^6}\times\frac{d}{b}\left\{-\frac{m^3}{120}+\frac{15}{112}m^5-\frac{1117}{672}m^7+\frac{1183}{96}m^9\right.$$

$$-\frac{21\times3641}{1024}m^{11}+\frac{11\times367{,}621}{10{,}240}m^{13}$$

$$\left.-\frac{143\times109{,}353}{8192}m^{15}+\ldots\right\}+\ldots$$

$$\left.+\frac{2\,b}{\pi\,q\,d\,N}\left(\operatorname{logh}\frac{p}{w}+0.14\right)\right] \qquad (\mathbf{13})$$

where $m^2=\dfrac{d^2}{d^2+4\,b^2}$

This formula is to be used in conjunction with (**8**). It should be used instead of (**10**) for practical problems, since it is more convenient and accurate. It appears longer than (**10**), but that is merely because more terms have been worked out. In reality, fewer terms of (**13**), than of (**10**), are needed to obtain the self-inductance of a given coil to a certain number of significant figures. The terms which are not needed can easily be neglected. For most coils made, the terms in c^6/d^6 will be found to be practically negligible, even for precision work.

The last term of formula (**13**) represents the effect of the air and insulation space between the conductors. It is assumed that the coil is wound with round wire or cable. If square wire is used, the constant 0.14 in the last term should be omitted. Therefore, for uniform current distribution over the section of the coil, as, for example, with square wire with infinitely thin insulation, the last term becomes zero. For precise work, the constant 0.14, which is an average value, should be changed in accordance with Dr. E. B. Rosa's results for various shapes of coils, given in the Bulletin of the Bureau of Standards, Vol. 3, 1907, page 37, and Vol. 8, No. 1, 1911, page 141.

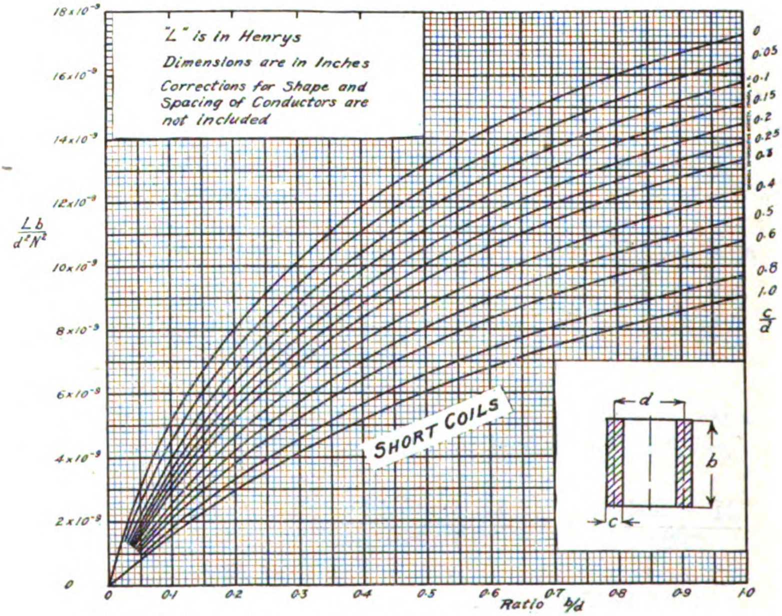

FIG. 6—SELF-INDUCTANCE OF SHORT REACTANCE COILS

A set of curves showing the self-inductance of cylindrical coils of various shapes, is given in Figs. 6 and 7. This should be useful for many engineering problems where precise accuracy is not required. The curves can give quicker and more accurate results for many cases than most approximate formulas.

The values of inductance of long coils in which c is almost as great as d, were calculated by a formula derived by the writer.* The values of inductance of coils considerably shorter than their mean diameter were derived from Tables C and D, by Prof. T. R. Lyle, Scientific Paper No. 320 of the Bureau of Standards, pages 569 and 570.

Example IV. To find the self-inductance of a coil wound with 1000 turns of round wire in 10 layers of 100 turns each.

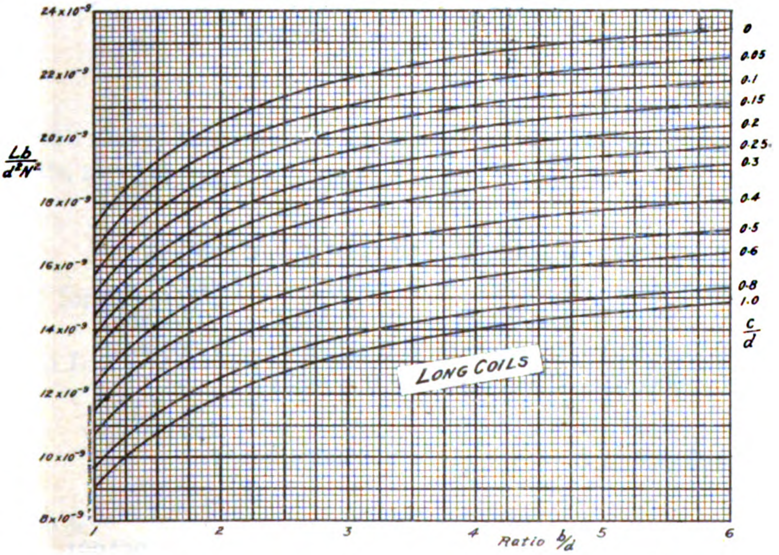

FIG. 7—SELF-INDUCTANCE OF LONG REACTANCE COILS

The diameter of the insulated wire is $p = 0.1$ cm. and the diameter of the bare wire is $w = 0.08$ cm. The mean diameter of the coil is $d = 10$ cm., the length is $b = 10$ cm., and the thickness is $c = 1$ cm. (Example I, Bulletin of the Bureau of Standards Vol. 4, No. 3, page 374.)

By formula (**11**), $m = \dfrac{1}{\sqrt{5}}$

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*Formula (5), "Self Inductance of Long Reactance Coils", by H. B. Dwight, *The Electrical World*, Feb. 9, 1918, page 300.

and L_s, in henrys, $= \dfrac{\pi^2 \times 10 \times N^2}{10^9}$ [1.118034 − 0.424413

$$- 0.005590 + 0.000559 - 0.000210 + 0.000059$$
$$- 0.000022 + 0.000008 - 0.000003]$$

$$= \frac{\pi^2 \times 10 \times N^2}{10^9} \times 0.688422$$

Table XXI, Scientific Paper No. 169, of the Bureau of Standards, gives

$$\frac{\pi^2 \times 10 \times N^2}{10^9} = 0.688423$$

By formula (**13**),

$$\Delta L = \frac{\pi^2 \times 10 \times N^2}{10^9} [- 0.066667 + 0.003333$$
$$+ 0.001880 - 0.000002 + \{0.000745 - 0.000186$$
$$+ 0.000060 - 0.000026 + 0.000012 - 0.000006$$
$$+ 0.000003 - 0.000002\} + \{0.0000012 - 0.0000008$$
$$+ 0.0000010 - 0.0000008 + 0.0000006 - 0.0000004$$
$$+ 0.0000003 - 0.0000002\} + 0.000231]$$

Therefore, $\Delta L = - \dfrac{\pi^2}{100} \times 0.060624$ henry.

By (**8**), $L = L_s + \Delta L = \dfrac{\pi^2}{100} \times 0.627798 = 0.061961$ henry.

The value given by (**9**) and (**10**) is 0.06194 henry.

The value given in the Bulletin of the Bureau of Standards, Vol. 4, No. 3, Exam. 1, page 374, is 0.061865 henry, which is less than 1/5 of 1 per cent different from the value given by (**13**). The result given in the above bulletin was obtained by Dr. E. B. Rosa's formula (91) Scientific Paper No. 169, of the Bureau of Standards. This formula has the advantage that it is equally applicable to coils of all lengths, whereas (**13**) is not very convergent for coils which are shorter than their mean diameter. Where (**13**) is convergent, however, it is more accurate.

Example V. Find the self-inductance of a coil of square wire with very thin insulation in which

$$\frac{b}{d} = 2, \quad \frac{c}{d} = \frac{1}{10} \text{ and } \frac{\pi^2 N^2 d^3}{8 b^2} = 10^6 \text{ abhenrys.}$$

(Example 9, Scientific Paper No. 320 of the Bureau of Standards, page 559).

By formula (11),

$$L_s = \frac{\pi^2 d^2 N^2}{b} [1.0307764 - 0.2122066 - 0.0004458$$

$$+ 0.0000131 - 0.0000015 + 0.0000001]$$

$$= \frac{\pi^2 d^2 N^2}{b} \times 0.8181357$$

Table XXI, Scientific Paper No. 169 of the Bureau of Standards, gives

$$L_s = \frac{\pi^2 d^2 N^2}{b} \times 0.818136$$

By formula (**13**),

$$\Delta L = \frac{\pi^2 d^2 N^2}{b} [- 0.066667 + 0.003333 + 0.000940$$

$$- 0.000001 + \{0.000202 - 0.000015 + 0.000001\}$$

$$+ \{0.0000003\}]$$

$$\Delta L = - \frac{\pi^2 d^2 N^2}{b} \times 0.062205 \text{ abhenrys.}$$

$$\Delta L = - 0.995286 \text{ millihenry.}$$

The value given by formula (29 A), Scientific Paper No. 320 of the Bureau of Standards, is

$$\Delta L = - 0.99526 \text{ millihenry.}$$

Example VI. A problem relating to a coil which is more similar to usual current-limiting reactors may be of interest. Find the self-inductance of a coil of mean diameter $d = 50$ inches, wound with 10 layers of cable, 75 turns per layer, two cables in parallel. The diameter of the cable is $w = 0.5$ in., and the distance from center to center of cables is $p = 1$ in. Therefore,

$$b = 75 \text{ in}, \quad c = 10 \text{ in.}, \quad q = 2, \text{ and } \quad N = 375.$$

By formula (**11**),

$$L_s \text{, in henrys, } = \frac{\pi^2 \times 50^2 \times 375^2}{0.3937 \times 10^9 \times 75} \times \frac{50}{150} [3.1623 - 0.8488 - 0.0040 + 0.0002]$$

$$= \frac{\pi^2 \times 50^2 \times 375^2}{0.3937 \times 10^9 \times 75} \times 0.7699$$

By formula (**13**),

$$\Delta L = \frac{\pi^2 \times 50^2 \times 375^2}{0.3937 \times 10^9 \times 75} \times [- 0.1333 + 0.0133 + 0.0031 + \{0.0014 - 0.0002\} + 0.0011]$$

$$\text{Therefore,} \quad L = \frac{\pi^2 \times 50^2 \times 375^2}{0.3937 \times 10^9 \times 75} \times [0.7699 - 0.1146]$$

$$= 0.07700 \text{ henry.}$$

The result, when calculated by (**9**) and (**10**) is the same.

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INHERENT LIMITATIONS ON TRANSFORMATIONS POSSIBLE BY STATIONARY APPARATUS

BY JOSEPH SLEPIAN

ABSTRACT OF PAPER

Expressions for electrostatic and electromagnetic energies, Joulian heat dissipation and power are given in complex quantities. The pure imaginary part of the expression for power in a static network is shown to be equal to 2 ω times the difference between the mean electromagnetic energy and mean electrostatic energy. Use is made of this new principle in considering the problems of power-factor correction and phase splitting. It is shown that in general for phase transforming by static apparatus both magnetic and electrostatic storage of energy are necessary, and it is shown how the minimum amounts of each are determined by the load.

The symmetry of the coefficients in the general equations for the steady state in a static network is demonstrated, and it is shown that limitations upon voltage and current transformations follow. The voltage regulation of any phase-splitting arrangement is considered.

CONTINUED failures in attempts to construct networks of stationary apparatus, which shall have certain characteristics, lead to the conviction that such characteristics are unattainable by static means. Examples are power-factor correction without condensers, single-phase to balanced polyphase transformations by condensers only or inductances only, or single-phase to polyphase transformations with inherent regulation for variable load. However convincing such failures may be, it is always satisfying to obtain general demonstrations of the impossibility of attainment of the characteristics desired, especially as the demonstrations generally reveal what characteristics can be obtained.

Considering the requirements of energy storage in the transforming apparatus, the problems mentioned above fall into two classes. In the problem of balanced power-factor correction, the instantaneous power drawn from any one phase is exactly equal to the instantaneous power supplied to the other phases. The instantaneous power supplied to the power-factor correcting apparatus is always zero. Hence there is no *a priori* reason for supposing a relation between the wattless power supplied

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by the apparatus and the electromagnetic energy stored up in the apparatus. In fact, there is no such relation when rotating machines are considered. The wattless power supplied by a synchronous condenser may be varied over a wide range without changing the kinetic energy or magnetic energy as determined by the flux, which is stored in the machine. For purely static apparatus, however, such a relation does exist as is shown in III. Even when the wattless power it supplies is balanced, a static network must have a minimum of energy storage, and this minimum varies with the magnitude of the wattless load.

In the problem of transformation from single-phase to balanced polyphase, there is an obvious requirement for energy storage irrespective of the character of the transforming apparatus. The power supplied by the single phase line has a double-frequency component and is pulsating. The power drawn by the balanced polyphase load, however, is continuous. Hence it is clear that the transforming apparatus must store up energy while the single-phase power is at its maximum, to be given out again while the single-phase power is at its minimum. This clearly calls for momentary energy storage, and therefore for a minimum mean energy storage dependent on the load. In rotating phase-converters, such as are in general use, the pulsations are in the kinetic energy of the rotor. The mean kinetic energy on the rotor is in general far in excess of the minimum mean energy called for by the nature of the transformation. This is because the heating limitations upon transforming electrical energy into mechanical are what determine the size of the rotor, rather than the energy considerations. If the heating limitations could be removed, the most economical rotating phase converter would be one in which the rotor would come to rest twice per cycle, and where the maximum velocity of the rotor would vary with the load. It is remarkable that networks of static apparatus can be devised which will effect the phase transformation with the minimum amount of energy storage called for above, provided that the polyphase power factor exceeds 0.707. This is shown in section 3. In such networks the condensers are without charge, and the reactors without flux simultaneously twice every cycle.

In all which follows, by static network is meant a network constructed of self and mutual inductors, condensers and resistors.

I. Power and Energy

Power and energy in an alternating current circuit are periodic and may be expanded into a Fourier series. If harmonics of current and voltage are absent, these Fourier developments consist only of two terms, a constant and a double-frequency term. The constant may in particular be zero. Thus strictly speaking, it is erroneous to speak of power and energy as double-frequency quantities. Actually they consist respectively of two components, one of zero frequency and one of double frequency. These two components are easily expressed in terms of complex voltage and current.

If $E = e_1 + j\,e_2$, a complex quantity, denotes an alternating e. m. f. in the usual way, the instantaneous e. m. f., e, is given by

$$e = \text{Real part of } (\sqrt{2}\,E\,\epsilon^{j\omega t}) = \sqrt{2}/2\,(E\,\epsilon^{j\omega t} + \hat{E}\,\epsilon^{-j\omega t})$$

where $\hat{E} = e_1 - j\,e_2$ is the complex number conjugate to E, that is having the same real part but with pure imaginary part of opposite sign.

Similarly, if I denotes an alternating current, its instantaneous value i is given by:

$$i = \text{real part of } (\sqrt{2}\,I\,\epsilon^{-j\omega t}) = \sqrt{2}/2\,(I\,\epsilon^{j\omega t} + \hat{I}\,\epsilon^{-j\omega t})$$

The instantaneous power p is given by the product of the instantaneous e. m. f. and the instantaneous current. Thus:

$$\begin{aligned} p &= 1/2\,(E\,\epsilon^{j\omega t} + \hat{E}\,\epsilon^{-j\omega t})\,(I\,\epsilon^{j\omega t} + \hat{I}\,\epsilon^{-j\omega t}) \\ &= 1/2\,(E\,\hat{I} + E\,I\,\epsilon^{2j\omega t} + \hat{E}\,I + \hat{E}\,\hat{I}\,\epsilon^{-2j\omega t}) \\ &= \text{real part of } (E\,\hat{I} + E\,I\,\epsilon^{2j\omega t}) \end{aligned}$$

Thus the instantaneous power consists of a constant component, real part of $E\,\hat{I}$, and a double-frequency component, real part of $E\,I\,\epsilon^{2j\omega t}$.

In the complex plane, the quantity $E\,\hat{I} + E\,I\,\epsilon^{2j\omega t}$ is represented by a point describing synchronously the perimeter of a circle whose center is the point $E\,\hat{I}$, and whose radius is the absolute value of $E\,I$. Since $E\,\hat{I}$ and $E\,I$ have the same absolute values, the circle passes through the origin.

It becomes clear at once from Fig. 1 that when $E\,\hat{I}$ is real and positive, the circle lies entirely to the right of the j axis, so that the power is always positive; when $E\,\hat{I}$ is pure imaginary, the circle has the j axis for a diameter so that the power is positive and negative respectively, half the time.

By the angle of a vector in the complex plane is meant the angle which it makes with the real axis. In Fig. 1, θ is the angle of $E\,\hat{I}$. The angle of the product of two vectors is the sum of the angles of the two vectors respectively. The angle of the conjugate of a vector is the negative of the angle of the vector. Hence, the angle of $E\,\hat{I}$ being the difference between angle of E and angle of I, is the angle of lag of I behind E. Hence:

$$\cos\theta = \text{power factor.}$$

$$\tan\theta = \frac{\text{Pure imaginary part of } E\,\hat{I}}{\text{Real part of } E\,\hat{I}}$$

In any balanced polyphase system, the e. m. fs. in the successive phases are given by E, $a\,E$, $a^2\,E$, ... $a^{n-1}\,E$, where a is a primitive complex nth root of unity. If $n = 3$, $a = -1/2 + j\,\sqrt{3}/2$.

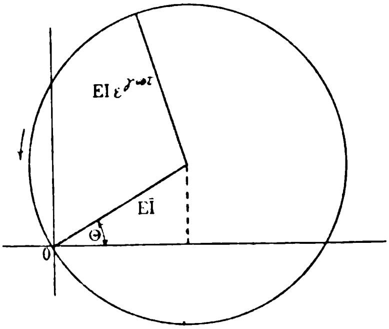

FIG. 1

It is readily seen that a is conjugate to a^{n-1}, a^2 is conjugate to a^{n-2}, etc.

If the phases are carrying balanced currents, they will be given by I, $a\,I$, $a^2\,I$, . . . $a^{n-1}\,I$.

To obtain the power we need the conjugates of the preceding quantities, and since the conjugate of a product is the product of the conjugates we get for the conjugate values, $\hat{I}$, $a^{n-1}\,\hat{I}$, $a^{n-2}\,\hat{I}$, . . . $a\,\hat{I}$.

The instantaneous power in the successive phases is, therefore, real part of $(E\,\hat{I} + E\,I\,\epsilon^{2j\omega t})$, real part of $(a\,E\,a^{n-1}\,\hat{I} + a\,E\,a\,I\,\epsilon^{2j\omega t})$, real part of $(a^2\,E\,a^{n-1}\,\hat{I} + a^2\,E\,a^2\,I\,\epsilon^{2j\omega t})$, etc.

Summing these up and noticing that $1 + a^2 + a^4 + \ldots a^{2(n-1)} = 0$ we get for the total power,

$$p = \text{real part of } (n\,E\hat{I}).$$

In a balanced polyphase system, the instantaneous power input is constant in time.

The instantaneous magnetic energy contained in a system of circuits magnetically coupled is:

$$t_m = 1/2\,(L_{11}\,i_1^2 + L_{22}\,i_2^2 + 2\,M_{12}\,i_1\,i_2 + \ldots)$$

where L_{11}, L_{22}, M_{12} etc. are the coefficients of self and mutual induction of the parts of the system. Substituting

$$i_1 = \sqrt{2}/2\,(I_1\,\epsilon^{j\omega t} + \hat{I}_1\,\epsilon^{-j\omega t}),\ i_2 = \sqrt{2}/2\,(I_2\,\epsilon^{j\omega t} + \hat{I}_2\,\epsilon^{-j\omega t}),\ \text{etc.},$$

$$\begin{aligned} t_m = {} & 1/2\,(L_{11}\,I_1\,\hat{I}_1 + L_{22}\,I_2\,\hat{I}_2 + M[I_1\,\hat{I}_2 + \hat{I}_1\,I_2] + \ldots) \\ & + 1/2\,(1/2\,[L_{11}\,I_1^2 + L_{22}\,I_2^2 + 2\,M_{12}\,I_1\,I_2 + \ldots]\,\epsilon^{2j\omega t} \\ & + 1/2\,[L_{11}\,\hat{I}_1^2 + L_{22}\,\hat{I}_2^2 + 2\,M_{12}\,\hat{I}_1\,\hat{I}_2 + \ldots]\,\epsilon^{-2j\omega t}) \\ = {} & T_m + \text{real part of } 1/2\,[L_{11}\,I_1^2 + L_{22}\,I_2^2 + 2\,M_{12}\,I_1\,I_2 + \ldots]\,\epsilon^{2j\omega t} \end{aligned}$$

$$T_m = 1/2\,(L_{11}\,I_1\,\hat{I}_1 + L_{22}\,I_2\,\hat{I}_2 + M\,[I_1\,\hat{I}_2 + \hat{I}_1\,I_2] + \ldots)$$

therefore represents the mean magnetic energy. It is always real and positive.

The instantaneous electrostatic energy in a group of condensers is $t_e = 1/2\left(\frac{q_1^2}{c_1} + \frac{q_2^2}{c_2} + \ldots\right)$

$$q_1 = \int i_1\,dt = \int \sqrt{2}/2\,(I_1\,\epsilon^{j\omega t} + \hat{I}_1\,\epsilon^{-j\omega t})\,dt$$

$$= \sqrt{2}/2\left(\frac{I_1}{j\,\omega}\,\epsilon^{j\omega t} + \frac{\hat{I}_1}{-\,j\,\omega}\,\epsilon^{-j\omega t}\right)$$

Similarly for $q_2\,q_3\ldots$ etc. Substituting in t_e

$$\begin{aligned} t_e = {} & 1/2\left(\frac{1}{c_1}\,\frac{I_1\,\hat{I}_1}{\omega^2} + \frac{1}{c_2}\,\frac{I_2\,\hat{I}_2}{\omega_2^2} + \ldots\right) \\ & + 1/2\left(1/2\left[-\,\frac{1}{c_1}\,\frac{I_1^2}{\omega^2} - \frac{1}{c_2}\,\frac{I_2^2}{\omega^2}\ldots\right]\epsilon^{2j\omega t}\right. \\ & \left. + 1/2\left[-\,\frac{1}{c_1}\,\frac{\hat{I}_1^2}{\omega^2} - \frac{1}{c_2}\,\frac{\hat{I}_2^2}{\omega^2}\ldots\right]\epsilon^{-2j\omega t}\right) \\ = {} & T_e + \text{real part of } 1/2[-\,1/c_1\,\frac{I_1^2}{\omega} - 1c_2\,\frac{I_2^2}{\omega^2} \\ & \ldots]\,\epsilon^{2j\omega t} \end{aligned}$$

$T_e = 1/2\left(\frac{1}{c_1}\,\frac{I_1\,\hat{I}_1}{\omega^2} + \frac{1}{c_2}\,\frac{I_2\,\hat{I}_2}{\omega^2} + \dots\right)$ therefore represents the mean electrostatic energy. It is always real and positive.

The instantaneous rate of heat generation in a system of resistors is $d = r_1\,i_1^2 + r_2\,i_2^2 + \dots$. Substituting the equivalent complex quantities:

$$d = (r_1\,I_1\,\hat{I}_1 + r_2\,I_2\,\hat{I}_2 + \dots) + 1/2\,\left([r_1\,I_1^2 + r_2\,I_2^2 + \dots]\,\epsilon^{2j\omega t} + [r_1\,\hat{I}_1^2 + r_2\,\hat{I}_2^2 + \dots]\,\epsilon^{-2j\omega t}\right)$$

$$= D + \text{real part of } 1/2\,[r_1\,I_1^2 + r_2\,I_2^2 + \dots]\,\epsilon^{2j\omega t}$$

$D = r_1\,I_1\,\hat{I}_1 + r_2\,I_2\,\hat{I}_2 + \dots$ gives the mean rate of energy dissipation into heat. It is always real and positive.

II. THE RELATION BETWEEN POWER, ELECTROSTATIC AND MAGNETIC ENERGY AND HEAT GENERATION

Suppose an arbitrary system of inductances, capacities and resistances given, having n terminals. Let $V_1, V_2 \dots V_n$, n complex numbers denote the potentials at these terminals, and $I_1, I_2, \dots I_n$ the currents at the terminals, taken positive when they flow into the system. Let $V_{n+1}, V_{n+2}, \dots$ etc., be the potentials at the nodes or junctions of the branches of the network. Let I_{kl} be the current *from* the node k *to* the node l. Thus $I_{kl} = -I_{lk}$. In what follows we shall include the n terminals among the nodes of the system.

Consider the expression

$\sum_k V_k\,(\hat{I}_{k1} + \hat{I}_{k2} + \dots)$. Since by Kirchhoff's laws $I_{k1} + I_{k2} + \dots = 0$ for every internal node, the whole must reduce to $V_1\,\hat{I}_1 + V_2\,\hat{I}_2 + \dots V_n\,\hat{I}_n$

$$\sum_k V_k\,(\hat{I}_{k1} + \hat{I}_{k2} + \dots) = V_1\,\hat{I}_1 + V_2\,\hat{I}_2 + \dots V_n\,\hat{I}_n \tag{1}$$

Take any branch a, joining two nodes, k and l. The current in the branch gives two terms in the above expression, namely:

$$V_k\,\hat{I}_{kl} + V_l\,\hat{I}_{lk} = V_k\,\hat{I}_{kl} - V_l\,\hat{I}_{kl} = (V_k - V_l)\,\hat{I}_{kl} = (V_k - V_l)\,\hat{I}_a$$

But $V_k - V_l = r_a\,I_a + j\,\omega\,(L_{aa}\,I_a + M_{ab}\,I_b + M_{ac}\,I_c + \dots) + \frac{1}{j\,\omega}\,\frac{1}{C_a}\,I_a$

Hence $$(V_k - V_l)\,\hat{I}_a = r_a I_a \hat{I}_a + j\,\omega\,(L_a I_a \hat{I}_a + M_{ab} I_b \hat{I}_a + M_{ac} I_c \hat{I}_a + \dots) - j\,\omega\left(\frac{1}{C_a}\,\frac{I_a \hat{I}_a}{\omega^2}\right)$$

Now write similar equations for the other branches. The left-hand sides will add up to the left-hand side of (1). The right-hand sides will add up to $D + 2j\,\omega\,(T_m - T_l)$
Hence:

$$V_1 \hat{I}_1 + V_2 \hat{I}_2 + \dots V_n \hat{I}_n = D + 2j\,\omega\,(T_m - T_l) \qquad \mathbf{(2)}$$

Hence the real part of $V_1 \hat{I}_1 + V_2 \hat{I}_2 + \dots V_n \hat{I}_n$ is the Joulian heat generated per second, and the pure imaginary part is $2j\,\omega$ times the mean magnetic energy minus the mean electrostatic energy.

III. APPLICATION OF THE RELATION, POWER FACTOR COMPENSATION

The principle enunciated in II is frequently useful in determining the possibilities of solution of certain problems, and the minimum amounts of magnetic and electrostatic energy storage necessary.

Let us consider first the problem of power factor correction in a polyphase system by static means. Because of the possibility of introducing arbitrary quadrature e.m.fs. in series with any phase by means of transformers placed across the other phases, many of us have tried to compensate for lagging power factor by means of transformers only. The constant failure of the schemes tried has convinced most of us that the idea is inherently impossible, but it is satisfying to have a definite proof of this fact.

The proposition is to insert a network between a polyphase supply and a lagging load so as to give unity power factor at the generator end. Sum up $V\hat{I}$ for all the terminals of the network. For the supply terminals, since $\cos\theta = 1$, $\Sigma V \hat{I}$ is real; the coefficient of j is zero. For the load terminals since leading currents are supplied *to* the network θ is negative. Hence the coefficient of j in $V\hat{I}$ for a load terminal must be negative. Its value is the wattless power supplied to the load through that terminal. Thus $V\hat{I}$ summed up for all the terminals must have for the coefficient of j the negative of the wattless power supplied the load. Hence by equation (**2**)

$$2\,\omega\,(T_e - T_m) = \text{wattless power of load.}$$

Hence in any such network there must be electrostatic storage of energy. In fact the minimum amount possible is $\frac{1}{2\,\omega}$ times the wattless power of the load.

IV. Phase Splitting

The use of condensers and reactances for changing from single phase to polyphase is well known. We shall here determine the minimum amounts of condenser and reactance energy storage necessary for this purpose. The impossibility of supplying a balanced polyphase load of lagging or unity power factor from a single-phase source by means of reactances alone will also be shown here.

Suppose then a network inserted between a single-phase source and a polyphase load such that the polyphase is balanced.

Summing up $V\,\hat{I}$ for the load terminals we get $-\,n\,E_2\,\hat{I}_2$ where E_2 is the polyphase voltage to neutral, and I_2 is the current per phase supplied *to* the load. Summing $V\,\hat{I}$ up for the supply terminals gives $E_1\,\hat{I}_1$ where E_1 is the single phase voltage and I_1 is the current taken from the supply. Hence for the network,

$$\Sigma\, V\,\hat{I} = E_1\,\hat{I}_1 - n\,E_2\,\hat{I}_2 = D + 2\,j\,\omega\,(T_m - T_e). \qquad \textbf{(2')}$$

The double-frequency component of power supplied by the single-phase source is real part of $E_1\,I_1\,\epsilon^{2j\omega t}$; that withdrawn by the load is zero as shown in II. This double frequency power must be supplying and removing energy from the magnetic and electrostatic fields in the network. The integral with respect to time of this double frequency component, real part of $\frac{1}{2\,j\,\omega}\,E_1\,I_1\,\epsilon^{2j\omega t}$ must give the double frequency component of the total energy stored. The mean value of all the energy stored added to the double frequency component must never be less than zero as energy can never be negative. Hence we must have

$$T_m + T_e \text{ is not less than absolute value of } \frac{1}{2\,j\,\omega}\;E_1\,I_1$$

$$2\,\omega(T_m + T_e) \text{ is not less than absolute value of } E_1\,I_1.$$

Now absolute value of $E_1\,I_1$ is the same as absolute value of

$E_1 \hat{I}_1$, and this, of course, is not less than the real part of $E_1 \hat{I}_1$. Using the symbol $\geqq$ for "greater than or equals":

$$2\,\omega\,(T_m + T_e) \geqq \text{absolute value of } E_1 \hat{I}_1 \geqq \text{real part of } E_1 I_1 \tag{3}$$

From equation (**2**)

$$2\,\omega\,(T_m - T_e) = \text{imaginary part of } E_1 \hat{I}_1 - \text{imaginary part of } n\,E_2 \hat{I}_2 \tag{4}$$

Subtracting (**4**) from (**3**)

$$4\,\omega\,T_e \geqq \text{absolute value of } E_1 \hat{I}_1 - \text{imaginary part of } E_1 \hat{I}_1 + \text{imaginary part of } n\,E_2 \hat{I}_2 \tag{5}$$

Adding (**3**) and (**4**) we get

$$4\,\omega\,T_m \geqq \text{absolute value of } E_1 \hat{I}_1 + \text{imaginary part of } E_1 \hat{I}_1 - \text{imaginary part of } n\,E_2 \hat{I}_2 \tag{6}$$

In equation (**5**) the first two terms on the right must clearly combine to give a positive quantity. If the polyphase load has a lagging power factor, imaginary part of $n\,E_2 \hat{I}_2$ will be positive. Hence in this case the right hand side of E will be positive, and not less than imaginary part of $n\,E_2 \hat{I}_2$. Thus with a lagging polyphase load, the minimum condenser energy storage for which a network can be constructed is given by:

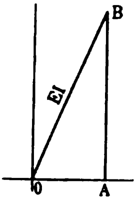

FIG. 2

$$4\,\omega\,T_e = \text{wattless power of load.} \tag{6'}$$

Actually, however, this limit cannot be reached, for to attain it we must make imaginary part of $E_1 \hat{I}_1$ equal absolute value of $E_1 \hat{I}_1$. Since, however, the real part of $E_1 \hat{I}_1$ is determined by the true polyphase power, this equality can be attained only as $E_1 \hat{I}_1$ becomes infinite. (See Fig. 2). Equation (**6**) shows that at the same time, T_m would have to become infinite.

Similarly for a leading polyphase load, the magnetic energy T_m cannot be less than $\frac{1}{4\,\omega}$ times the wattless polyphase power. To actually attain this value, however, would require zero single phase power factor and infinite electrostatic energy.

A case of special interest is where the single phase power factor is unity. In this case the imaginary part of $E_1 \hat{I}_1$ is zero, and the absolute value of $E_1 \hat{I}_1$ equals the true single phase power. Hence (**5**) and (**6**) become:

$$4\,\omega\,T_e \geqq \text{Single phase power} + \text{polyphase wattless power (lagging)}. \qquad (\mathbf{5''})$$

$$4\,\omega\,T_m \geqq \text{Single phase power} - \text{polyphase wattless power (lagging)}. \qquad (\mathbf{6''})$$

Networks are well known, which effect phase splitting with the minimum of condenser and reactance energy storage indicated above. We now see that it is impossible to do better in this respect.

When the polyphase load has a power factor less than cos 45 deg. then if network losses are negligible, equation (**6''**) shows that reactance may be dispensed with while still keeping unity power factor on the single phase.

If a phase splitting network employs the minimum amount of energy storage, the total instantaneous energy stored must be zero twice every cycle. When the inductance energy is zero, the inductance voltages are a maximum. When the condenser energy is zero, the condenser voltages are zero. Hence in such a network all the inductance voltages are in phase with each other and in quadrature with the condenser voltages.

IV. THE RECIPROCAL RELATION

Suppose a system of terminal potentials $V_1\,V_2\,.\,.\,.\,V_n$ applied to the terminals of a network produces the terminal currents $I_1, I_2\,.\,.\,.\,I_n$. Suppose a different system of terminal potentials $V_1', V_2', \ldots V_n'$ produces the terminal currents $I_1', I_2', \ldots I_n'$. Then

$$V_1\,I_1' + V_2\,I_2' + \ldots\,V_n\,I_n' = V_1'\,I_1 + V_2'\,I_2 + \ldots\,V_n'\,I_n \qquad (\mathbf{7})$$

Such reciprocal relations are well known in mathematical physics. The proof as given below follows the lines of the proofs usually given.

Using the notation of II, we have at once:

$$\sum_k V_k\,(I_{k1}' + I_{k2}' + I_{k3}' + \ldots) = V_1\,I_1' + V_2\,I_2' + \ldots\,V_n\,I_n' \qquad (\mathbf{8})$$

Any branch a joining the nodes k and l contributes two terms to the left hand member of (**8**), namely: $V_k\,I_{kl}' + V_l\,I_{lk}'$.

But

$$V_k I_{kl}' + V_l I_{lk}' = V_k I_{kl}' - V_l I_l' = I_a' (V_k - V_l)$$

$$= I_a' \left[r_a I_a + j\,\omega\,(L_{aa} I_a + M_{ab} I_b + \ldots) + \frac{1}{j\,\omega} \frac{I_a}{C_a} \right]$$

$$= r_a I_a I_a' + j\,\omega\,(L_{aa} I_a I_a' + M_{ab} I_a' I_b + M_{ac} I_a' I_c + \ldots) + \frac{1}{j\,\omega} \frac{I_a I_a'}{C_a}$$

Summing up for all the branches gives

$$\Sigma V_k (I_{k1}' + I_{k2}' + \ldots) = r_a I_a I_a' + r_b I_b I_b' + \ldots . + j\,\omega\,(L_{aa} I_a I_a' + L_{bb} I_b I_b' + M_{ab} I_a I_b' + M_{ba} I_a' I_b + \ldots) + \frac{1}{j\,\omega} \left(\frac{I_a I_a'}{C_a} + \frac{I_b I_b'}{C_b} + \ldots \right) \qquad (9)$$

Similarly, by summing up $\sum\limits_k V_k' (I_{k1} + I_{k2} + \ldots)$ first by nodes and then by branches,

$$\Sigma V_k' (I_{k1} + I_{k2} + \ldots .) = V_1' I_1 + V_2' I_2 + \ldots V_n' I_n \qquad (8')$$

$$\sum_k V_k' (I_{k1} + I_{k2} + \ldots .) = r_a I_a I_a' + r_b I_b I_b' + \ldots + j\,\omega\,(L_{aa} I_a' I_a + L_{bb} I_b' I_b + M_{ab} I_a' I_b + M_{ba} I_a I_b' + \ldots) + \frac{1}{j\,\omega} \left(\frac{I_a' I_a}{C_a} + \frac{I_b' I_b}{C_b} + \ldots \right) \qquad (9')$$

Hence comparing (**8**) (**9**) (**8′**) and (**9′**) we see that

$$V_1 I_1' + V_2 V_2' + \ldots V_n I_n' = V_1' I_1 + V_2' I_2 + \ldots V_n' I_n \qquad (7)$$

From equation (**7**) follows at once the well known reciprocal properties of a network. For example; suppose we supply one volt to the terminal 1 of a network keeping the other terminals at zero voltage. A certain current I_2 will flow at terminal 2. Now suppose we apply one volt at terminal 2 keeping the other terminals at zero potential. A certain current I_1' will flow at terminal 1. Now substituting for V_1, $V_2, \ldots V_n$ the values 1, 0, 0, . . . 0, and for $V_1', V_2', \ldots V_n'$ the values 0, 1, 0. . . . 0, in equation (7) we find:

$$I_1' = I_2$$

That is, a volt placed at terminal 1 produces the same current at terminal 2 as one volt placed at terminal 2 would produce at terminal 1.

In the next section we shall be concerned principally with four terminal networks in which the currents in pairs of terminals are constrained to be equal and opposite. For this special case, putting $n = 4$ in equation (7) and $I_3 = -I_1$, $I_4 = -I_2$, $I_3' = -I_1'$, $I_4' = -I_2'$, we get:

$$(V_1 - V_3)\,I_1' + (V_2 - V_4)\,I_2' = (V_1' - V_3')\,I_1 + (V_2' - V_4')I_2$$

Setting $V_1 - V_3 = E_1$, $V_2 - V_4 = E_2$, $V_1' - V_3' = E_1'$ and $V_2' - V_4' = E_2'$. We find,

$$E_1 I_1' + E_2 I_2' = E_1' I_1 + E_2' I_2 \qquad (7')$$

From this equation we deduce at once this following reciprocal relation. One volt difference of potential placed at one pair of terminals will circulate the same amount of current through a short circuit at the other pair of terminals as one volt difference of potential placed at the second pair will circulate through a short circuit at the first pair.

V. THE GENERAL SINGLE PHASE TRANSFORMING NETWORK

Any network having four terminals may be used to receive current at some voltage at one pair of terminals and delivering current at some other voltage or phase at the other pair of terminals. We propose to investigate here what are the limitations on such transformations by purely static means.

The solution in detail for the steady state in any network can always be obtained by means of Kirchhoff's Laws generalized for complex quantities. Given the currents I_1 and I_2 in the two pairs of terminals, which we shall now call the primary and secondary terminals, E_1 and E_2 the primary and secondary voltages may be calculated. Now the equations given by Kirchhoff's laws are all linear in the unknowns. The process of solving them only involves linear operations. Hence E_1 and E_2 must be linear functions of I_1 and I_2. Thus:

$$E_1 = a\,I_1 + b\,I_2$$
$$E_2 = b'\,I_1 + cI_2 \qquad (\mathbf{8})$$

Here the quantities a, b, b', c are complex numbers. However, it is easily seen that they are not independent.

In fact, applying the reciprocal relation ($\mathbf{7}'$) we find:

$$E_1\,I_1' + E_2\,I_2' = a\,I_1\,I_1' + b\,I_2\,I_1' + b'\,I_1\,I_2' + c\,I_2\,I_2'$$

and $E_1'\,I_1 + E_2'\,I_2 = a\,I_1\,I_1' + b\,I_2'\,I_1 + b'\,I_1'\,I_2 + c\,I_2'\,I_2$

Hence $b\,I_2\,I_1' + b'\,I_1\,I_2' = b\,I_2'\,I_1 + b'\,I_1'\,I_2$

Hence $b\,(I_2\,I_1' - I_2'\,I_1) = b'\,(I_1'\,I_2 - I_1\,I_2')$

Therefore: $b = b'$

Thus the primary and secondary voltages and currents of any network of the kind we are considering always satisfy relations of the form:

$$E_1 = (a_1 + j\,a_2)\,I_1 + (b_1 + j\,b_2)\,I_2$$
$$E_2 = (b_1 + j\,b_2)\,I_2 + (c_1 + j\,c_2)\,I_2 \qquad (\mathbf{8}')$$

What is the significance of the real and pure imaginary parts of the coefficients in ($\mathbf{8}'$). Forming the power expression we have:

$$\begin{aligned} E_1\,\hat{I}_1 + E_2\,\hat{I}_2 &= [a_1\,I_1\,\hat{I}_1 + b_1\,(I_2\,\hat{I}_1 + I_1\,\hat{I}_2) + c_1\,I_2\,\hat{I}_2] \\ &\quad + j[a_2\,I_1\,\hat{I}_1 + b_2\,(I_2\,\hat{I}_1 + I_1\,\hat{I}_2) + c_2\,I_2\,\hat{I}_2] \\ &= D + 2\,j\,\omega\,(T_m - T_e) \end{aligned}$$

Since the two brackets are real, the first must equal D the rate of generation of Joulian heat. If there are no losses in the network the first bracket must be zero, and the coefficients a, b, c must be pure imaginary.

Since we are interested in the inherent limitations upon the transformation possibilities of an ideal network, that is, one in which the losses are zero, we shall assume in all that follows that a, b, and c are pure imaginary.

$$a = j\,A$$
$$b = j\,B$$
$$c = j\,C$$

where $A\ B\ C$ are real. The network equations then are:

$$E_1 = j\,A\,I_1 + j\,B\,I_2$$
$$E_2 = j\,B\,I_1 + j\,C\,I_2 \qquad (\mathbf{8}'')$$

Let us first consider the possibility of a constant potential constant potential transformation. Given E_1 constant, we require E_2 to be independent of the load, I_2.
Eliminating I_1 in (**8**″) we obtain:

$$E_2 = B/A\, E_1 + \left(\frac{B^2 - A\,C}{j\,A} \right) I_2 \qquad \textbf{(9)}$$

E_2 can be independent of I_2 only if $B^2 - A\,C = 0$. This is the condition for perfect coupling. Furthermore, the coefficient of E is real. Hence we conclude, in any constant potential to constant potential transformation without losses, the transformed potential must agree in phase with the primary potential.

Next consider a constant potential constant current transformation. Solving (**8**″) for I_2 we get:

$$I_2 = -\,j\,B\,E_1 + \left(\frac{j\,A}{B^2 - A\,C} \right) E_2 \qquad \textbf{(10)}$$

I_2 is independent of E_2 only if $A = 0$. Furthermore the coefficient of E_1, is pure imaginary. Hence in any constant potential constant current transformation without losses the secondary current is in quadrature with the primary voltage.

Let us now discuss the problem of determining a network such that for a given secondary load the secondary voltage shall be in quadrature with the primary voltage, and the primary power factor shall have a predetermined value.

The load can be given in terms of its admittance, $y_2 = g_2 - j\,b_2$. The primary power factor can be determined by giving the apparent primary admittance, $I_1 E_1 = y_1 = g_1 - j\,b_1$ Since there are no losses in the network we must have $g_1 = g_2 = g$.

What restrictions do the above conditions impose upon A, B, C? Substituting $I_1 = (g - j\,b_1)\,E_1$, $I_2 = -\,(g - j\,b_2)\,E_2$, and $E_2 = j\,E_1$ in (8″), we get:

$$E_1 = j\,(g - j\,b_1)\,A\,E_1 + j(-\,g + j\,b_2)\,j\,B\,E_1$$

$$j\,E_1 = j\,(g - j\,b_1)\,B\,E_1 + j\,(-\,g + j\,b_2)\,j\,C\,E_1$$

Simplifying:

$$1 = b_1\,A + g\,b + j\,(g\,A - b_2\,B)$$

$$1 = g\,B - b_2\,C + j\,(-\,b_1\,B - g\,C)$$

Separating the real and imaginary parts of these two equations, we get:

$$1 = b_1 A + g B$$
$$0 = g A - b_2 B$$
$$1 = g B - b_2 C$$
$$0 = b_1 B + g C$$

Solving we find:

$$A = \frac{b_2}{b_1 b_2 + g^2} \qquad B = \frac{g}{b_1 b_2 + g^2} \qquad C = \frac{-b_1}{b_1 b_2 + g^2}$$

Thus we see that *A*, *B*, and *C* are completely determined by the conditions imposed on the network. But *A*, *B*, *C* determine entirely the secondary voltage in terms of the secondary current. Hence we conclude, all networks without losses which effect phase quadrature for a given load with given primary power factor have the same inherent regulation of secondary voltage as the secondary load is varied.

REFERENCES

The relation between wattless power and electrostatic and magnetic energies given in II, was discovered independently by the author. Since this paper was submitted to the Institute the same relation was proved in a different manner by J. B. Pomey, *Revue Generale de l'electricite*, Vol. III, 9, pp. 315–319. March 2, 1918.

The relation has subsequently been generalized by the author to include rotating commutatorless machines, with many interesting conclusions.

Examples of reciprocal relations such as are given in IV may be found in Maxwell, "Electricity and Magnetism", third edition, pp. 105 and 405.

April 15, 1919.

To be presented at a joint meeting of the American Institute of Electrical Engineers and the Institute of Radio Engineers, New York, October 1, 1919.

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TRANSATLANTIC RADIO COMMUNICATION

BY E. F. W. ALEXANDERSON

ABSTRACT OF PAPER

The paper defines the state of the art of today which is the result of developments during the war. Transatlantic radio communication is at present maintained by five first class stations, two in America and three in Europe. These stations operate at wave-lengths between 12,500 and 17,000 meters. The range of wave-lengths suited for such traffic is rather limited, the desirable wave length being included between the limits of 10,000 to 20,000 meters. New developments indicate three methods for increasing the radio traffic without interference between the different messages. These methods are increase of the transmitting speed, closer spacing of wave lengths and directive reception. If these technical possibilities are intelligently used, the author predicts that radio communication will be equal to all demands that will be placed upon it.

The second part of the paper describes the radio transmitting system for the development of which the author is responsible. This system is represented by the naval radio station, New Brunswick, N. J. and comprises new means for generating modulating, and radiating the continuous wave energy. The generator is the high-frequency alternator with which the author's name has become associated. The modulating system is the "magnetic amplifier" which is described in a paper by the author before the Institute of Radio Engineers. The "multiple antenna" system of radiation is described in this paper for the first time. The general theory and figures for the increased radiation efficiency are given. The author also predicts that the multiple antenna will make possible directive radiation on a large scale.

It has already become generally known that a new highway for world traffic has been opened up through the development of transatlantic radio communication. It is now a matter of history that radio was largely used for communication between the United States and armies in Europe and that the Great War was brought to a close by negotiations conducted by radio which led to the armistice. Now, we are ready for an international commerce of unprecedented scope, but lack adequate means for communication.

The recent achievements of radio technique have become common knowledge, and the world has now turned to this new method of communication clamouring that it step in and save

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the day. This is a condition which places a serious responsibility upon radio engineers. Fortunately, the technique has emerged from the cloud of mystery that used to surround it, and we are in position to treat the problem cooly and scientifically like any other problem in electrical engineering. However, it must not be inferred that the task is any easy one, if the radio technique is to fulfill all the hopes which are placed on it.

It has been demonstrated during the war period that transoceanic communication has become thoroughly reliable, every day in the year, and practically every hour in the day. Thus far, we can say, that the problem is solved. But a second question will be raised: What volume of traffic can be carried by the means at our disposal at the present time, and what is the relation of this radio traffic to the world traffic of to-day and to the world traffic of the future? The facts of the case are briefly the following:

Experience has shown that the wave lengths which are most suited for transoceanic communication lie between 12,000 and 17,000 meters. "This space in the ether" has already been taken up by five first class transmitting stations which, during the war period and up to the present time, have been in continuous service for transatlantic communication. Of these stations, two are in the United States, one in England, one in France and one in Germany. By extending the range of wave lengths down to 10,000 and up to 20,000 meters, and following the same system of intervals there would be room for about seven more stations or a total of twelve first class transmitting stations.

A first class station has such radiating power that its messages can be received in all parts of the world. This is one of the advantages of radio communication; but it implies that if such a station is to be used to full advantage it must have a "right of way" for its wave length over the whole world. Thus if we look at the matter pessimistically, without allowance for the improvements that further engineering developments are likely to bring, it would look as if the capacity of the world for first class radio stations would be about twelve. The rate of transmission at the present time from these stations is about twenty words a minute and it would thus be easy to figure out that the capacity of radio for handling any considerable portion of world communication would be totally inadequate.

The other side of the picture, which the radio engineer of the future must study carefully and closely, should indicate the technical possibilities for improving the situation. The tendency of present day developments points to the following means for expansion of radio traffic:

1. Increase in speed of transmission.
2. Improved selectivity based on the direction of the wave.
3. Improved selectivity making possible closer spacing of wave lengths.

As a basis of discussing the general situation it may be here stated as simple facts:

1. That signals have been transmitted and received at considerably more than 100 words a minute.
2. That signals have been received from Europe while an American high power station within comparatively short distance was radiating on the same wave length.
3. That is has proved practical to separate radio signals differing in wave length considerably less than 1 per cent.

Based on these facts, it is probable that the transmitting speed in the future will average 100 words a minute instead of 20 words a minute.

That the selectivity for direction of the waves will multiply by five the number of stations that may be operated on one wave length; and that the selectivity with reference to wave length will be improved so that the wave lengths of messages will be within 1 per cent of each other, instead of 7 per cent which is the spacing of the stations at present.

These prospects, taken in combination, give us an optimistic picture in which the possible capacity for transoceanic radio traffic of the world is 175 times as great as it is with the practise of to-day.

To claim that the traffic capacity could immediately be increased nearly 200 times, would be an exaggeration, because the different improvements which have been made may partly conflict with the execution of each other if they are to be used simultaneously. This optimistic picture is therefore to be regarded as a goal—perhaps never to be reached, but it points the way for almost unlimited possibilities for progress by continued engineering efforts.

In order to avail ourselves of these three improvements simultaneously, the transmitted wave must be a continuous wave which does not "spill over" with harmonics, decrements or variations, into the range of wave length assigned for other communication. When wave lengths are spaced 1 per cent apart, each wave must be sufficiently pure so as to have no objectionable components outside the limits of one-half of one per cent. While rules to this effect should be rigidly enforced it must be appreciated that there are certain fundamental limitations.

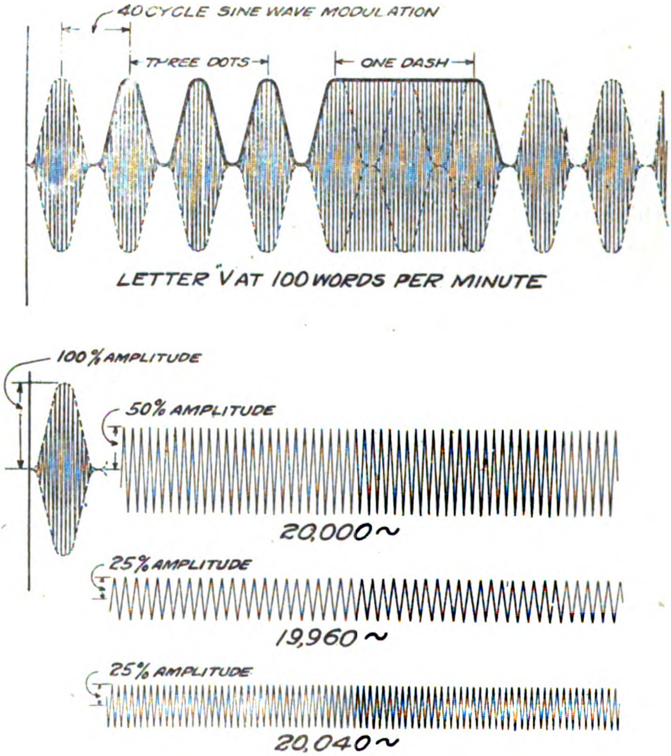


FIG. 1—METHOD OF RESOLVING SINE WAVE MODULATION INTO THREE CONTINUOUS WAVES

HIGH SPEED SIGNALING

Modern transoceanic radio signaling is conducted by means of continuous waves. It must be appreciated, however, that signaling by an absolutely continuous wave would be impossible, because the making of dots and dashes introduces increments and decrements in the radiation. It will be shown that a repetition of increments and decrements can be resolved into a group of closely adjacent continuous waves. This agrees with the well known fact that the tuning of a wave with a decrement is known as a broad tuning. To illustrate this point we may take as a basis a signal at 100 words a minute (5 letters per word). If it is assumed that the increments and decrements in making the dots are not sharp interruptions but a continued variation by sine wave curves as indicated in Fig. 1, it is found by an analysis that such a wave may be resolved into a group of continuous wave components within the limits of 40 cycles above and below the average. This is the theoretical minimum width of the band of wave lengths which are necessary to transmit 100 words per minute. If the dots are defined by sharper interruptions the wave becomes still "broader" and it would not be unreasonable to say that the minimum practical band of wave lengths for 100 words per minute is 100 cycles on each side of the fundamental. This would make possible a spacing of the waves 1 per cent apart when using a wave length of approximately 15,000 meters. Messages at a higher rate of speed will occupy a correspondingly wider "space in ether."

As a conclusion from this analysis it may thus be said that an increase of the speed to 100 words a minute and increase of messages to a spacing 1 per cent apart may be accomplished simultaneously provided that waves are used of such a character and modulation that they contain no radiation except the one needed to accomplish the intended purpose.

DIRECTIVE RECEPTION

The second means for increasing radio traffic consists in improving the selectivity by taking advantage of the direction of the waves. The author's paper printed in the *Proceedings* of the Institute of Radio Engineers, August, 1919, described a receiver referred to as the "Barrage Receiver" which was used to demonstrate directive reception. There are several other types of receiving devices, developed by the United States Navy and other investigators, which accomplish substantially the same purpose. The broad principle underlying all these directional receiving devices is the one discovered by Bellini and Tosi and generally referred to under their names.

In the U. S. Navy's tests of the "Barrage Receiver", it was proven that it is possible to carry on simultaneous two-way communication on exactly the same wave length. If this method of directive reception is carried out consistently in a world system of communication, it may be assumed that transmitting stations operating on the same wave length may be located approximately as shown in the map in Fig. 2—one in Europe, one on the American east coast, one on the American west coast, one in the Far East and one in South America. The American receiving station for European signals in such a system should be located east of the American Atlantic Transmitting Station, and in line with the Pacific Transmitting Station. Thus messages from the two American transmitting stations could both be simultaneously neutralized in the American Receiving station by a "Barrage Receiver," while signals on the same wave length are received from Europe. Interference from the South American station may be neutralized by the use of a double barrage system, while the station in the Far East, though it may not be exactly in line with the two others would be sufficiently near the general direction so that, considering the great distance, it would not cause interference.

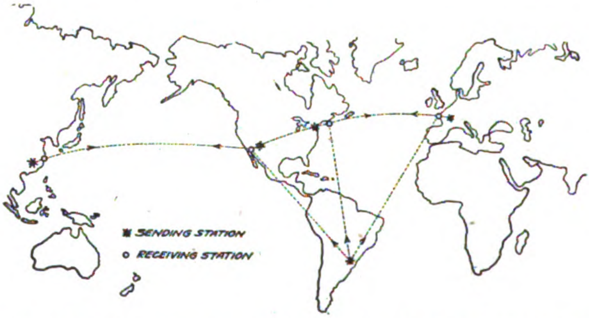
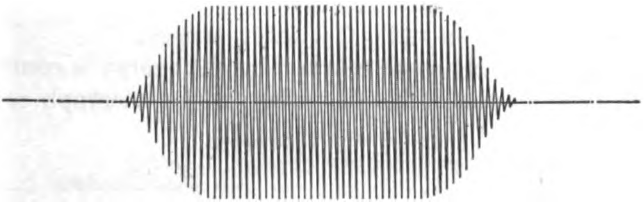


Fig. 2—Proposed Simultaneous Radio Transmissions on the Same Wave Length

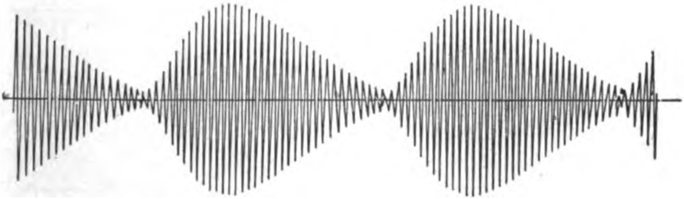
If this communication system is to be duplicated on a number of other wave lengths, the practical conclusion follows that the transmitting stations as well as receiving stations for each district should be grouped in centers, and these centers located relatively so as to make the directive neutralization as effective as possible. The neutralization of several transmitting stations simultaneously may not always work out as first designed. It has been shown by investigations of the Navy Department that the radio waves do not always follow straight lines and not always the same path. However, discrepancies from such origin may again be overcome by further extending the principle of neutralizing waves from several directions simultaneously.

CLOSER SPACING OF WAVE LENGTHS

The method of increasing traffic capacity by closer spacing of wave lengths has great possibilities. It has been shown that the selectivity with reference to wave length can be greatly increased by several successive tunings in either the radio, the audio or some intermediate circuit. It is thus entirely practical to receive either by ear or by photographic records, signals which are considerably less than 100 cycles apart. The theoretical limits for such selectivity in connection with high speed transmission are defined below. As illustrated in Fig. 1, a high speed message is not a single continuous wave, but a band of wave lengths—100 words per minute occupying a space of about 200 cycles. Therefore the same degree of selectivity is not to be expected with a high-speed signal if the interfering radiation is of considerable intensity.



WAVE TRAIN SHOWING ACTUAL NUMBER OF RADIO CYCLES IN A DOT OF THE TELEGRAPH CODE TRANSMITTED AT THE RATE OF 500 WORDS PER MINUTE AT 15,000 METERS WAVE LENGTH.



A SPARK WAVE AT 400 CYCLES SPARK FREQUENCY

FIG. 3

Speaking in terms more familiar to practical radio operators it may be said that high speed telegraph signals assume to some degree the objectionable characteristics of a spark signal. As an illustration of this, Fig. 3 shows the relative decrements in a continuous high-speed telegraph wave and a spark wave, showing that the increments and decrements of the continuous wave signal at 500 words per minute are about equal to a spark wave of 400 sparks per second. These illustrations apply to wave lengths of about 15,000 meters.

THE RADIO TRANSMITTING SYSTEM

Several types of radio transmitting systems are at present in use with a high degree of success. The descriptive matter in this paper will, however, be confined to the system for which the author is responsible as represented by the Naval Radio Station at New Brunswick, N. J.

Generally speaking, any radio transmitting system consists of three essential elements:

1. The generator of radio frequency energy.
2. The modulating system, whereby the energy is controlled so as to produce the dots and dashes of the telegraph code or the modulations of the human voice.
3. The antenna or radiating system.

GENERATING SYSTEM

There are four types of generating systems of high-frequency energy in use at the present time.

1. The spark or impulse generator.
2. The Poulsen-Arc generator.
3. The high-frequency alternator.
4. The vacuum tube oscillator.

The system which will be described, is of the type employing a high-frequency alternator. The installation of New Brunswick contains a 50-kw. alternator shown in Fig. 4 which was operated for sometime for experimental purposes with radio telephony at a wave length of 8000 meters, and later in transatlantic telegraph service at 9300 meters.

A larger equipment which has been in continuous service for the last year consists of a 200 kw. alternator shown in Fig. 5, 6 and 7. Fig. 5 shows the machine partly assembled, the rotor consisting of a solid steel disk. The spaces between the polar projections are filled with non-magnetic material so as to present a smooth surface and thereby reduce air friction to a minimum. The disk runs between the two laminated armatures which are cooled by water pipes as shown in the photograph. The armature winding which consists of wire wound back and forth in straight open slots, is divided in 64

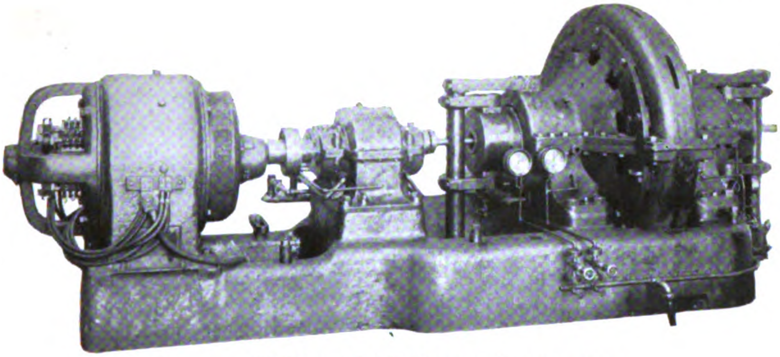


FIG. 4—50-KW. 50,000-CYCLE ALTERNATOR

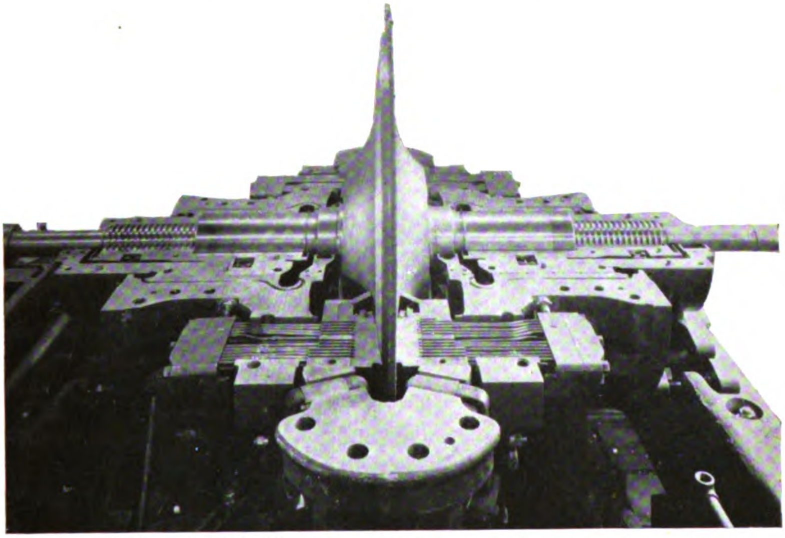
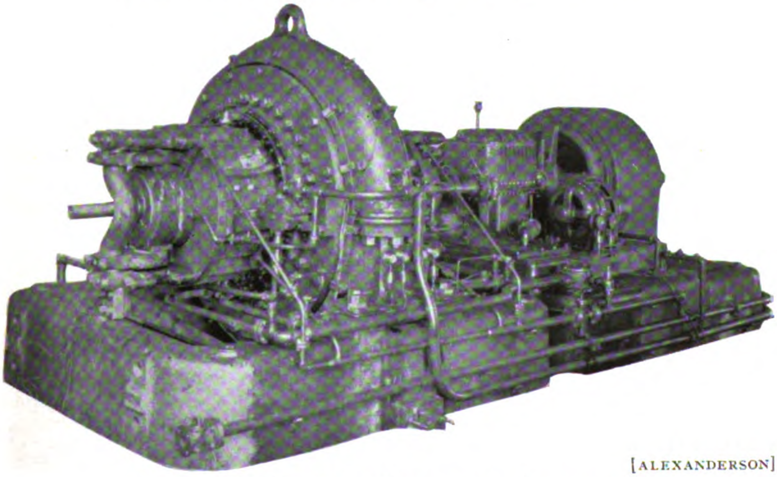


FIG. 5—200-KW. HIGH-FREQUENCY ALTERNATOR



[ALEXANDERSON]

FIG. 6—200-KW. HIGH-FREQUENCY ALTERNATOR

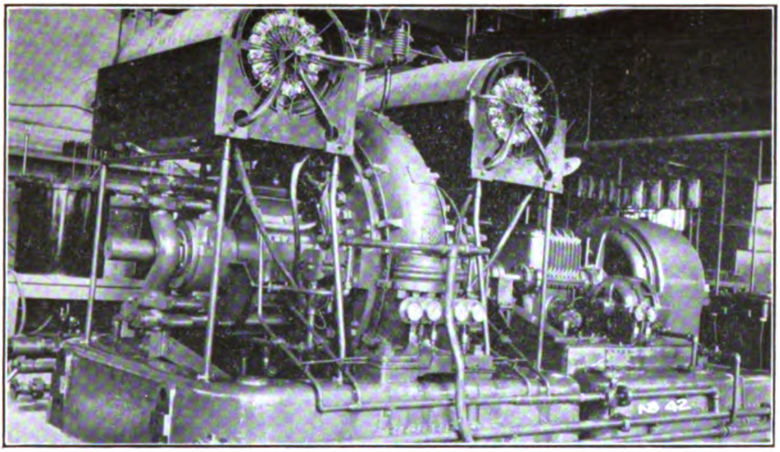
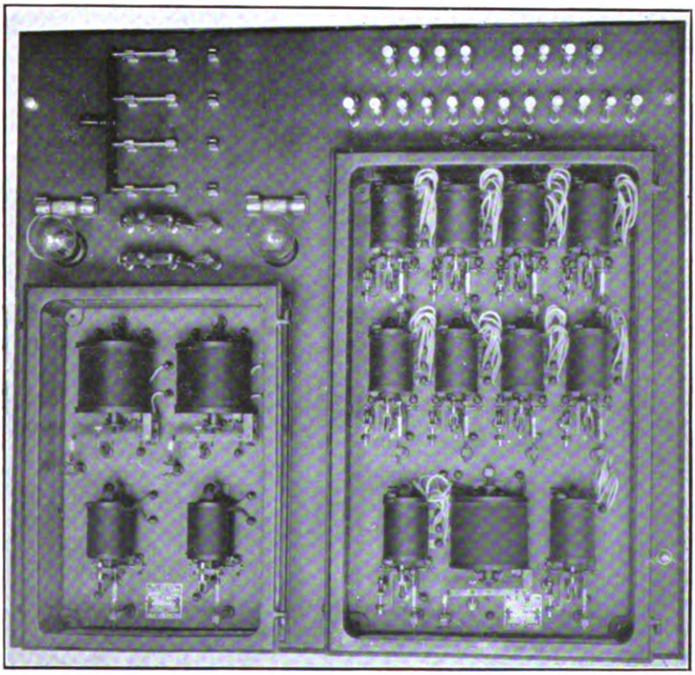


FIG. 7—200-KW. ALTERNATOR SET AS INSTALLED IN THE NAVAL RADIO STATION, NEW BRUNSWICK, NEW JERSEY



[ALEXANDERSON]

FIG. 9—COMBINED CURRENT AND VOLTAGE REGULATORS FOR HIGH-FREQUENCY ALTERNATOR CONTROL

sections, each section generating about 100 volts and 30 amperes. The current generated by these 64 windings is collected in the air core transformer mounted on the top of the machine, Fig. 7. This transformer has 64 independent primary windings corresponding to the armature windings. The single secondary winding of the transformer delivers the complete output of the alternator. This collecting transformer is thus to be considered as an integral part of the generating unit and for all purposes of calculation the characteristics of the generating unit, such as electromotive force and current, are given as delivered from this secondary winding. At full output the alternator delivers 100 amperes at an electromotive force of 2000 volts. It can thus be seen that the alternator is designed for a load resistance of 20 ohms. However, the same machine might be adapted for any other load resistance by selecting a different number of turns in the secondary of the collecting transformer. The reason why this particular machine is designed for a high voltage and low current will be given later in discussion of the new type of antenna with which it is used.

The 200-kw. alternator when operated at the New Brunswick wave length of 13,600 meters runs at a speed of 2170 rev. per min. It is driven by an induction motor through a gear of a ratio of 2.97:1 when the high frequency alternator is used as a source of radiation, the wave length is determined directly by the rotative speed of the machine. Thus, obviously, it is important that the rotative speed should be as nearly absolutely constant as it is possible to make it. An important accessory of the alternator set is therefore the speed regulator. The 50-kw. alternator set shown in Fig. 3 is driven by a direct-current motor whereas, the 200-kw. set is driven by an induction motor of the slip ring type. The 50-kw. set was equipped with a direct-current motor because the problem of speed regulation of that type of motor is somewhat easier. Induction motors were, however, decided upon for the later types because alternating current power is more easily available in most localities.

SPEED REGULATOR

The speed regulator consists of a speed determining element and a power controlling element. The speed determining element is a resonant high-frequency circuit fed by one of the 64 alternator windings which is set aside for that purpose. The oscillating energy of this high-frequency circuit is associated by magnetic couplings with a rectifying circuit in which the high-frequency energy is changed into direct current. This rectified current in turn, actuates the controlling magnet of a vibrating regulator of the type that is generally used for voltage regulation in power stations. When the driving motor is a direct-current motor it is easy to see how this vibrating regulator may be made to control the speed by regulating the voltage of the power supply to the motor. In order to accomplish the same object with an induction motor some new features have been introduced.

An ordinary induction motor is operated at constant potential. When the motor runs light it draws from the line a magnetizing current which is almost wattless. Thus it operates at a low power factor. When the motor is fully loaded it draws power at a high power factor—a motor of the type used having a power factor of 90 per cent.

When the New Brunswick station was adjusted for operation it was found that a wave length was desired which required the induction motor to work at 19 per cent slip. The rheostat in the secondary of the motor could easily be adjusted so that the motor would deliver the desired power with full load at 19 per cent slip. However, inasmuch, as the output of the alternator varies continually with the making of dots and dashes of the telegraph code, the motor is alternately loaded and not loaded. The tendency would therefore be for the motor to speed up during the intervals. If the potential of the power supply to an induction motor is varied, the motor torque varies by the square of the voltage. It is furthermore easy to show, by the theory of the induction motor, that if a motor consumes power at 90 per cent power factor at full load, and the load is reduced to ¼ by the reduction of voltage to ½, the power factor will remain 90 per cent. In fact it will always consume power at 90 per cent power factor regardless of its load if the voltage supply is adjusted accordingly, so long as the secondary resistance remains constant and the speed remains constant.

Thus it may be said that the standard method of operating an induction motor is at constant potential and variable power factor. The method of operating the driving motor of the radio set may on the other hand be characterized as variable potential and constant power factor.

The problem which thus presented itself was to find means for varying the applied voltage in accordance with action of the speed-determining element, and this has been done in the following way:

Between the motor and the power supply is introduced a choke coil with iron core, the permeability of which can be varied by saturation. The change in permeability is produced by a direct current which is controlled by a vibrating regulator. When the motor carries full load the iron core is saturated so that the choking effect is practically zero. At fractional load the choking effect is automatically adjusted by the regulator so that the motor delivers at all times the power required to hold constant speed. The motor itself operates at all times at its maximum efficiency and power factor, but the power factor of the current drawn from the line varies with the load. Thus when the motor operates at ¼ load the power factor of the line is 45 per cent while the power factor of the motor is 90 per cent. The circuits of the regulator are shown in Fig. 8 and the vibrator regulator in Fig. 9.

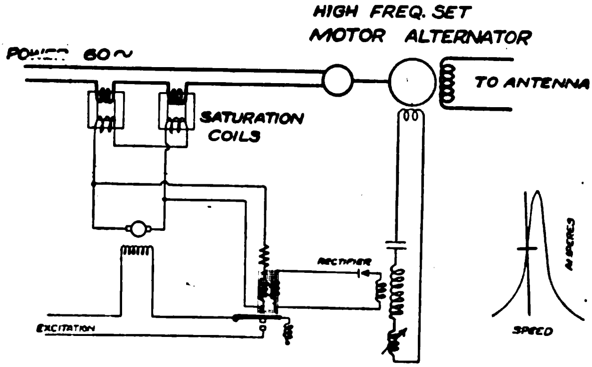


FIG. 8—SPEED REGULATOR ALTERNATING CURRENT DRIVE

MODULATING SYSTEM

The method of controlling high-frequency energy involves an apparatus which has become known as the "magnetic amplifier." This device is described in a paper by the author in the Institute of Radio Engineers, January, 1916, and therefore needs to be referred to only briefly. The magnetic amplifier is a device which is physically of the nature of an oil cooled transformer. The iron core which is made of fine laminations, is designed in such a way that the magnetic permeability of the iron core can be varied by magnetic saturation. By a special combination of tuned circuits as shown in Fig. 10 it has become possible to separate the controlling current from the high-frequency current so that a comparatively weak current of a few amperes controls as many hundreds of amperes in the antenna. When the transmitting station is used for telegraphy the magnetic amplifier is controlled by the telegraph relays which are a part of the wire telegraph system. During the war service, the telegraph key was operated in the centralized operating room of the Naval Communication Department in Washington. When the station is used for telephony the controlling current is an amplified telephone current.

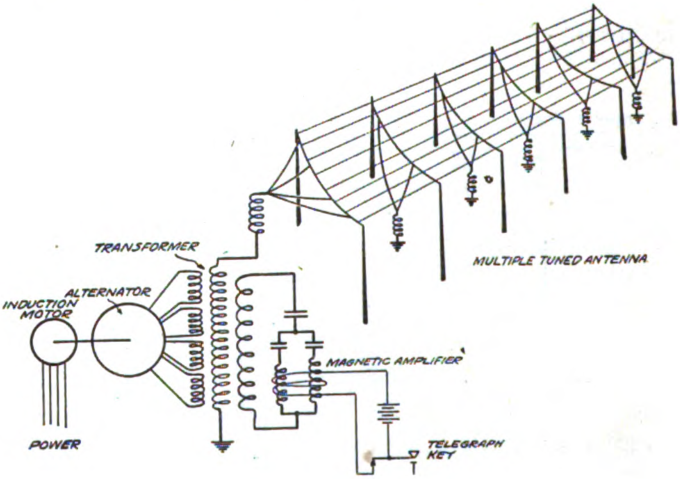
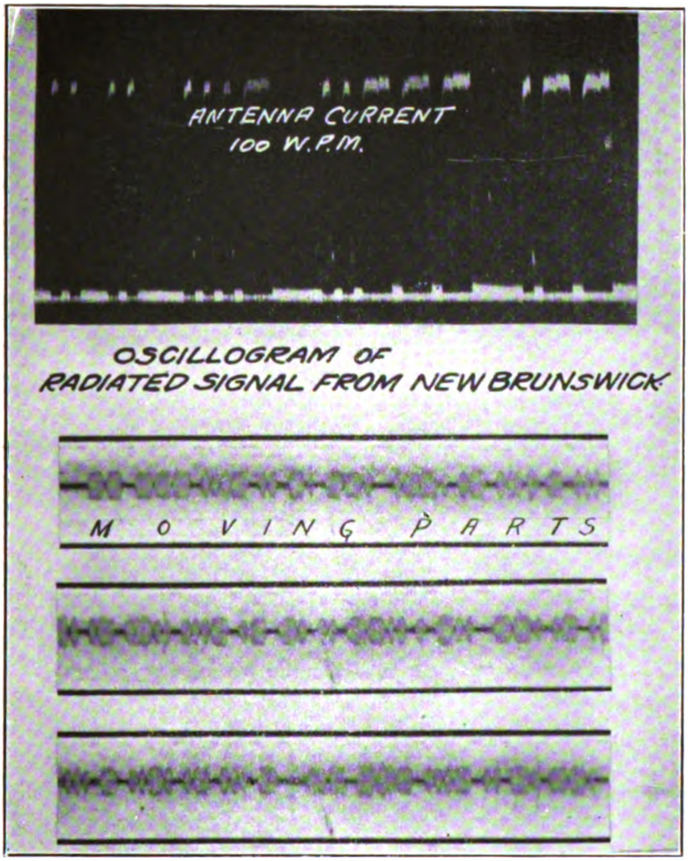


FIG. 10

While the magnetic amplifier has proven to be a very satisfactory and reliable controlling device for ordinary telegraphy its particular advantages are most prominent in high-speed telegraphic transmission and telephonic transmission, on account of its instantaneous magnetic action without any arcing contacts. Fig. 11 shows an oscillogram of radiation at 100 words per minute and a copy of a photographic record of reception at the same speed. Fig. 12 shows the telephone modulation of the antenna current when Secretary Daniels was speaking over the telephone line from Washington, controlling the output from the New Brunswick station, thereby transmitting his voice to President Wilson's ship at sea.



[ALEXANDERSON]

FIG. 11—PHOTOGRAPH OF RECEIVED SIGNAL FROM NEW BRUNSWICK AT 100 WORDS PER MINUTE

THE MULTIPLE ANTENNA

The antenna of the New Brunswick station represents a new departure in the method of radiation. The old antenna structure was originally one of the horizontal Marconi antenna, 5000 ft. (1500 m.) long, 600 ft. (180 m.) wide supported on towers 400 ft. (120 m.) high. The original antenna had a resistance of 3.8 ohms.

The antenna as operated now has a resistance of 0.5 ohms distributed approximately as follows:

Radiation resistance	0.07 ohms
Tuning coils and insulation	0.10
Ground resistance	0.33
Total multiple resistance	0.5 ohms

The reduction in total resistance of the antenna is due to the reduction of the ground resistance. While the old antenna had one tuning coil located in one end, the new antenna has six tuning coils as shown in Fig. 10 and Fig. 13.

THEORY OF THE MULTIPLE ANTENNA

The theory of the multiple antenna can be explained in several ways. Without going into details, an explanation will be presented giving the point of view which has proved most useful for general discussion. For this purpose the multiple antenna may be considered as an aggregate of several antennas of the ordinary vertical type each having its own tuning coil. When regarded in this way, the multiple antenna in New Brunswick is equivalent to six independent radiators placed 1000 ft. apart. The ground resistance of each of the radiators is 2 ohms, the coil resistance 0.6 ohms and the radiation 0.07 ohms making a total resistance of 2.67 ohms. Each of these radiators has an aerial 1000 ft. long and 600 ft. wide, counted at an average height of 300 ft. A total resistance of about 2.67 ohms is, as a matter of fact, the resistance to be expected from an antenna of such dimensions and ordinary design. If one individual antenna such as described is operated with a radiation of 100 amperes, the energy consumption of the antenna would be 26.7 kw., and the radiation efficiency would be 0.07 ohm divided by 2.67 ohm which is 2.6 per cent. If it is desired to increase the radiation from 100 amperes to 600 amperes the energy consumption would be 36 times as great that is, 960 kw. There is, however, another way to produce a radiation equivalent to 600 amperes. If six separate antennas of the dimensions described were built and each operated with a radiation of 100 amperes, each antenna would emit a system of waves proportional to 100 amperes radiation. If all the waves emitted by the six antennas were in phase, the amplitude of the combined wave would be six times as great as the wave emitted by one antenna. Thus the amplitude of the combined wave would be equal to the amplitude of the wave emitted by one antenna when operated at 600 amperes. The energy consumption required for operating one antenna was 26.7 kw., thus it might off-hand be concluded that the energy consumption required for operating the six antennas simultaneously would be 160 kw. This conclusion is not exactly correct because there is an interaction between the radiating effects of the different antennas resulting in a somewhat higher energy consumption. This might be expressed as follows:

The radiation resistance which is 0.07 ohm is common for all six antennas, whereas the ground and coil resistance of 2.6 ohm belongs to the different antennas, individually. Thus the combined circuit of the multiple antenna can be represented by the common radiating resistance of 0.07 ohm connected in series with a group of six multiple resistance of 2.6 ohms each, so that the total current of 600 amperes flows through the 0.07 ohm radiation resistances which represent the ground and coil resistance of the individual antennas. Hence the total energy consumption of the combined antenna is found to be 180 kw. out of which 155 kw. is ground coil and insulation loss and 25 kw. radiation. The radiation efficiency of the multiple antenna is thus 14 per cent against the radiation efficiency of 2.6 per cent for the individual antenna. The above calculation is made for the present operating wave of 13,600 meters. If on the other hand the same calculation is made for the same length of 8000 meters, which has been found more efficient for telephonic transmission, it is found that the radiation efficiency is 30 per cent, the energy being distributed as follows:

Radiation resistance..........	0.2 ohms
Coil and insulation...........	0.07
Ground resistance............	0.33
Total multiple resistance.....	0.6 ohms

For the sake of convenience in dealing with the radiation from a multiple antenna it has become the practise to indicate the total radiation from the multiple antenna as the sum of the currents measured in the six ground connections. The equivalent multiple resistance of the antenna is then determined by the equation I^2R = energy consumption, where I is the sum of the currents in the ground connection.

It has been assumed above that each of the individual antennas is operated so that the waves sent out by the same are not only of the same frequency, but exactly of the same phase. It remains to be shown how this is accomplished. Fig. 13 shows the relation between the antenna and the multiple tuning coils and the alternator. As shown by the diagram, the alternator is connected in series with one of the six tuning coils. Arrows on the diagram indicate further how the oscillating currents and the energy currents are distributed. Six independent oscillating circuits are formed, the current in each ground connection corresponding to the charging current of the corresponding section of the aerial. If the antenna had been shock excited so that it continued to oscillate in the way indicated, no current would flow in the horizontal wires between the different sections of the antenna. However, in order to maintain continued oscillations a flow of energy must take place from the alternator which is connected to one of

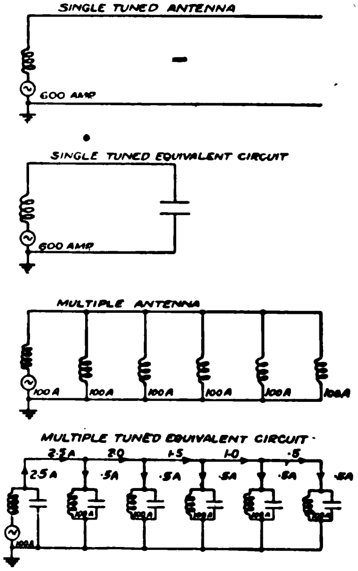


FIG. 13

the six tuning coils. When the antenna is operated with 100 amperes in each of the ground connections, the energy consumption as shown above is 180 kw., that is, each oscillating circuit consumes 30 kw.

What actually takes place is the following: The tuning coil to which the alternator is connected transforms the energy of the alternator into a power supply at a potential of 60,000 volts, and each of the oscillating circuits draws energy from this power supply at that voltage. Thus the energy currents consumed by each oscillating circuit is only 0.5 amperes. It can thus be seen that while the total oscillating current of the antenna is 600 amperes the energy current which flows horizontally from the power source to the multiple oscillating circuits is only a total of 2.5 amperes. In other words, the energy which is delivered by the first tuning coil in the form of 100 amperes at 1800 volts is transformed by the first oscillating circuit and distributed as in a transmission line from which 0.5 amperes at 60,000 volts is drawn in five places. The analogy between the multiple antenna and a high-tension power distribution system is thus apparent.

This point of view is a departure from the conventional theory of radiation; but it must be remembered that there was a time in the development of electric power technique when the introduction of the high-tension multiple distribution system was a radical departure.

DIRECTIVE RADIATION

The multiple antenna as described in its simplest form is adjusted so that the radiation from each of the individual oscillators is in phase. If, however, the antenna dimensions are so chosen that the phase displacement of the traveling wave between the different radiators becomes an essential factor, it is possible to obtain directive radiation. The radiated wave then will not be a simple circular wave but an interference pattern which may be treated like the corresponding phenomena in light and sound waves. Furthermore the phase displacement of the oscillations of the individual radiators may be regulated by tuning. Thus a variety of interference patterns may be created and analysis of these possibilities shows that an efficient unidirectional radiation by such methods should be possible.

Methods for unidirectional radiation have been established

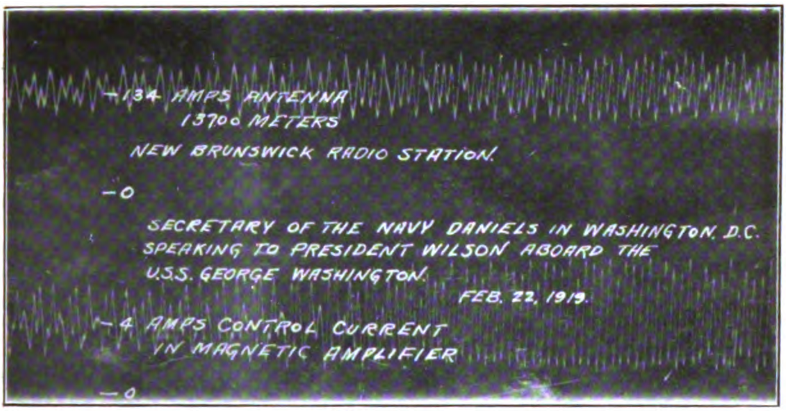


FIG. 12

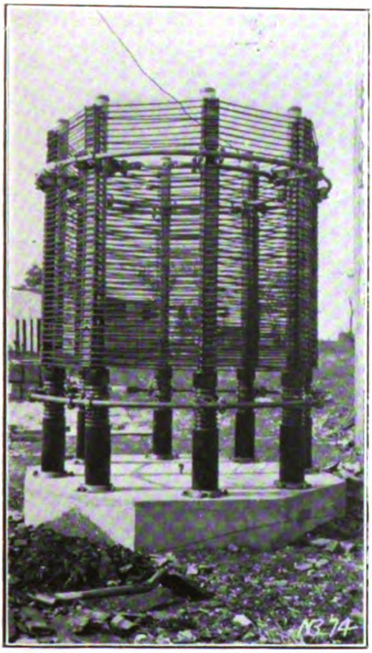
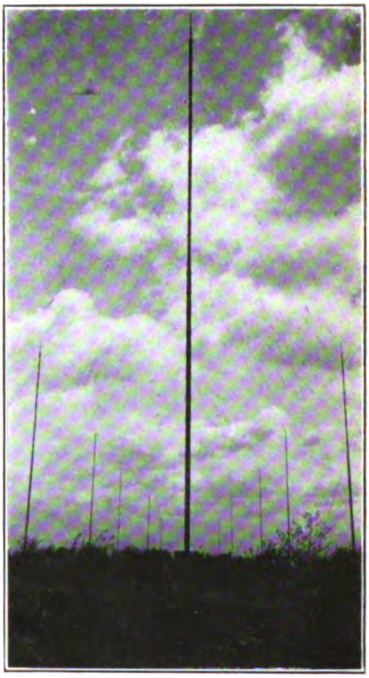


FIG. 14—OUTDOOR TUNING COIL



[ALEXANDERSON]

FIG. 15—PERSPECTIVE OF ANTENNA

through the well known work of Bellini and Tosi. Through the courtesy of Mr. Bouthillon of the French Post Office, results of tests made in France have been placed at the disposal of the author, which show conclusively directive radiation by the Bellini and Tosi antenna.

With the dimensions of antennas used up to the present time, efficient directive radiation has not been practical. It has, however, been proved by various tests that the system of a central power source and a distribution system of energy to a large number of multiple radiators places at our disposal means for constructing radiators of dimensions of one wave length or more. The New Brunswick antenna (1500 meters long) has a minimum wave length of 8000 meters as a single antenna, whereas it can be operated as a multiple antenna at 2000 meters wave length. A detailed analysis of the possibilities of multiple radiation would fall outside the scope of this paper but the author is in position to predict with confidence that directive radiation on a large scale will not only prove practical but that it will be the most efficient method of radiation.

To add directive radiation to the proposed program for increasing the capacity of radio traffic would perhaps be premature until it has been demonstrated on a large scale. However, it deserves mention in order to show that new principles which may be utilized for still greater expansion of the radio technique have not yet been exhausted.

To be presented at a joint meeting of the American Institute of Electrical Engineers and the Institute of Radio Engineers, New York, October 1, 1919.

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PRINCIPLES OF RADIO TRANSMISSION AND RECEPTION WITH ANTENNA AND COIL AERIALS

BY J. H. DELLINGER

ABSTRACT OF PAPER

Coil aerials are coming to replace the large antennas in radio work. The advantage of the coil aerial as a direction finder, interference preventer, reducer of strays and submarine aerial, make it important to know how effective such an aerial is as a transmitting and receiving device in comparison with the ordinary antenna. In this article the mathematical theory is presented and, as a result, the answer to this question is obtained. Experiments have verified the conclusions reached, and the formulas which are obtained are a valuable aid in the design of an aerial to fit any kind of radio station.

A great many questions and hazy ideas on the behavior of radio waves are cleared up by the study which was made and here presented.

It is found that the coil aerial is particularly desirable for communication on short wave lengths. A coil aerial is as powerful as an antenna only when its dimensions approach those of the antenna. For other reasons, however, a small coil aerial is in many cases as effective as a large antenna.

It is shown that an advantageous type of radio aerial is a condenser consisting of two large metal plates. This type of aerial has many of the advantages of the coil aerial.

The fundamental principles of design of aerials are given in this paper. On the basis of this work the actual functioning of any type of radio aerial can be determined either from measurements made upon the aerials or from actual transmission experiments.

The investigation has opened up a large and most interesting field for further research and progress in the utilization of radio waves.

I. INTRODUCTION

IN a radio transmitting or receiving set, either the condenser or the inductance coil is made of large dimensions. It is then called the aerial, and effects the transfer of power between the radio circuits and the ether. The coil aerial has the inherent advantage of serving as a direction finder and interference preventer, but is less effective quantitatively as a transmitting or receiving device than the condenser type of aerial, commonly called the antenna. Both kinds of aerial are very simple in construction, consisting merely of one or more wires. An antenna

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Manuscript of this paper was received September 1, 1919.

consists of a wire or set of wires connected in parallel and constituting one plate of a condenser, the other plate being the ground beneath. The coil aerial is one or more turns of wire constituting a simple coil or loop. When an antenna is used its circuit is completed, in general, by placing an inductance coil in series with it and the ground; and when a coil aerial is used its circuit is completed by connecting a condenser across its terminals. The typical connections are shown in Figs. 1 and 2.

The antenna is used when it is desired to communicate over as great a range as possible or reduce the power of the apparatus as much as possible. The coil is used when directional properties are particularly important. The coil radiates and receives electric waves better in the direction of its plane than in the direction of its axis, whereas the performance of the antenna is much more nearly independent of direction of the waves. By arranging a coil so that it can rotate it makes an excellent direction finder. When thus used on a ship or an airplane, a coil aerial is sometimes called a radio compass. It has also been called a radio goniometer. By turning it so that its axis is parallel to the direction of propagation of the waves from some particular station, that wave is not received while waves from other directions are received. The coil may thus serve as an interference preventer. It is possible to attain some slight reduction of the effects of strays, commonly called static, by using combinations of coil aerials. Submarine communication is more successful with coil aerials than with antennas because the coil can be protected from the short-circuiting effect of the water while an antenna can not. The numerous advantages of the coil aerial make it highly im-

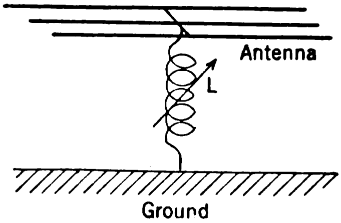

FIG. 1—SIMPLE ANTENNA CIRCUIT

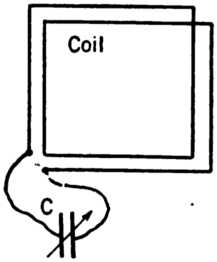

FIG. 2—SIMPLE COIL AERIAL CIRCUIT

portant to know the relative sensitiveness or power of transmission of the device in comparison with the antenna. This publication provides the answer to this question and sets forth the theory of radiation and reception and the action of antenna and coil aerials. The relative effectiveness of any coil and antenna is given by formula (**32**) to (**36**) in Sec. IV 1 below. The uses of the coil as a direction finder, interference preventer, reducer of strays, and submarine aerial, are not treated in this article.

The most important question considered is the practical one: How far can communication be maintained by the use of any specified antennas or coil aerials. Formulas are developed by which the current received in an antenna or coil is calculated in terms of the current in a transmitting antenna or coil, resistance of receiving aerial circuit, the distance, wave length, and dimensions of the aerials. The formulas have been found to be useful in the design of aerials and in the selection of an aerial for a particular kind of communication. They were worked out before there was any experimental information available to answer the question of the comparative quantitative value of the two kinds of aerials. Not much information on this has been obtained from experiment even yet (1919), but such experiments as have been made have substantiated the formulas. The work described in this paper was done in 1916 and 1917. The results were given in "Radio Transmission Formulas," a confidential paper of July, 1917, which was circulated in the Signal Corps and Navy. Publication was withheld during the war at the request of the Signal Corps. The formulas have also been given by the writer of the present paper on page 234 of "The Principles Underlying Radio Communication," 1918, Signal Corps Pamphlet No. 40, a book which can be purchased from the Superintendent of Documents, Washington, D. C.

Historical. The coil aerial and the condenser aerial (antenna) both date back to the first experimenter with the electric waves that make radio telegraphy possible. H. Hertz in 1888 used an open oscillator, which was the forerunner of the antenna, as his transmitting apparatus. For receiving he used a circle of wire, which was the first loop or coil aerial, and observed its directional properties.

The possibility of a loop or coil aerial as a transmitting device was discussed from the theoretical standpoint by G. F. Fitzgerald and later by J. A. Fleming, in *Electrician*, 59, pp. 936, 976, 1016; 1907. Fleming derived expressions for the radiated fields, using a curious theory in which the four sides of the coil were replaced by Hertzian doublets.

The use of a large loop or single-turn coil as an aerial in practical radio communication was described by G. Pickard in Proceedings of the Wireless Institute of America, 1, May 1, 1909. He discussed its properties both as a radiation and receiving aerial. He described its use as a direction finder, stating that he had determined directions with it to better than 1 degree.

In spite of this work and proposals by others, the antenna was used almost exclusively as the transmitting and receiving device until 1913. The use of the coil aerial received a great impetus by the publication of an article by F. Braun in *Jahrbuch der drahtlosen Telegraphie und Telephonie*, 8, p. 1, 1914; on the Use of Closed Circuits in Place of Open in Radio Telegraphy. He discussed the advantages of a coil aerial as a receiver and transmitter, both from the theoretical and the experimental standpoint.

Since 1913 there has been a great deal of development work done on coil aerials and they were extensively used in the war. The development of the coil aerial as a practical direction finder and receiving device was begun at the Bureau of Standards in 1915. Using electron tubes as the detecting apparatus, transatlantic signals were received on a coil inside a room. Experiments with the coil as a transmitting device were carried out at the Bureau in 1917. Among the very few published treatments of development and use of the coil aerial are those in Bucher's text-book, "Practical Wireless Telegraphy" 1917, p. 256; and "Radio Direction-Finding Apparatus" by A. S. Blatterman, *Electrical World*, 73, p. 464; 1919. Most of the descriptions to date have been confidential reports of the military services of various countries.

The theoretical discussions by Fleming and Braun are cumbersome and needlessly complicated and the results are not well adapted to practical use. The present paper presents an original treatment that is relatively very simple but none the less exact and leads to conclusions that apply directly to practical work. This paper also points out a number of misconceptions that have existed, and endeavors to clear up some of the controversial points on the radiation of waves and the functioning of aerials.

II. DERIVATIONS OF THEORETICAL FORMULAS

1. RADIATION FROM AN ANTENNA

Formula (**8**) below, giving the radiated magnetic field at a distance from an antenna, is a well-known formula. It has been given by various writers, and is the only one presented in this paper that requires any deep consideration of fundamental electromagnetic theory. The result is in fact implicit in Maxwell's classical treatise, "Electricity and Magnetism". The derivation given here is much more direct and brief than the others the author has seen, and is given only for that reason. The derivations of formula (**10**) and following ones are still simpler, and will be of more interest to most readers.

The units used in this paper are international electric units, the ordinary electric units based on the ohm, ampere, centimeter, and second. (See paper by the author on "International System of Electric and Magnetic Units", Scientific Paper of the Bureau of Standards No. 292). The unit of magnetic field intensity is the gilbert per cm., often called the cgs. unit. The only exception to the use of units of the international system is in certain of the practical formulas where lengths are expressed in meters or miles where so stated.

In the following discussion is calculated the magnetic field intensity produced by a flat-top antenna, having electric current of uniform value throughout the length of the vertical portion. Most antennas in practise approximate closely this condition.

The symbols used are:

i = instantaneous current
I_0 = maximum value of current
I = effective value of current
H_t = instantaneous value of magnetic field intensity
H_0 = maximum value of magnetic field intensity
H = effective value of magnetic field intensity
h = height of aerial
d = distance from sending aerial
ω = 2π times frequency of the current
t = time
λ = wave length
c = velocity of electric waves = 3×10^{10} cm. per second
Subscripts s = sending, r = receiving, a = antenna, c = coil.

In Fig. 3 the upper heavy line represents the flat top of the antenna, and the lower heavy line the grounding area. Suppose a current is flowing, having the instantaneous value i in the vertical portion. The magnetic field intensity at any point due to a varying current is different from that due to a steady current. Consequently the field cannot be calculated in the same way that the magnetic field intensity of a straight wire is ordinarily calculated. When the current is varying, the magnetic field intensity is calculated by the aid of a quantity called the vector potential in such a way that the variation with time is taken into account. The instantaneous value of the vector potential of current in the vertical conductor at a distance d in a plane perpendicular to the conductor, is

$$A = \frac{[i]\,h}{d} \tag{1}$$

where $[i]$ indicates that for any time t the value of i is taken for the instant $(t - d/c)$.

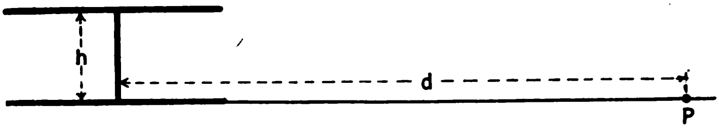

FIG. 3—CALCULATION OF MAGNETIC FIELD AT A DISTANCE FROM AN ANTENNA

Suppose the current in the antenna is a sine-wave alternating current,

$$i = I_0 \sin \omega t \tag{2}$$

$$\therefore [i] = I_0 \sin \omega (t - d/c)$$

$$A = \frac{h\,[i]}{d} = \frac{h\,I_0}{d} \sin \omega (t - d/c) \tag{3}$$

The magnetic field intensity is calculated from the vector potential by the general relation $H_t = 0.1 \text{ curl } A$, which for this simple case of a straight conductor becomes

$$H_t = \frac{1}{10} \frac{\partial A}{\partial d} \tag{4}$$

the direction of H_t being perpendicular to the plane of h and d. From equation (3),

$$H_t = -\frac{h\,\omega\,I_0}{10\,c\,d} \cos \omega (t - d/c) - \frac{h\,I_0}{10\,d^2} \sin \omega (t - d/c) \tag{5}$$

This equation gives the magnetic field intensity at any point P at a distance d from the antenna. The second term represents the ordinary induction field associated with the current, while the first term is the radiation field. At a considerable distance the second term is negligible because the second power of d occurs in the denominator. The first term then represents the magnetic field radiated from an antenna at the distance d from the antenna. The distance d is measured along the earth's surface, because the waves follow the curvature of the earth's surface instead of proceeding straight out into space. For a considerable distance from the antenna, the maximum value of the magnetic field intensity during a cycle is therefore

$$H_0 = \frac{h \omega I_0}{10 c d}$$

Expressing in terms of effective values,

$$H = \frac{h \omega I}{10 c d} \tag{6}$$

Henceforth H means the radiated field unless it is specifically stated to be the total field. The last equation may be expressed in terms of wave length instead of ω by the relation

$$\frac{\omega}{c} = \frac{2 \pi}{\lambda} \tag{7}$$

$$\therefore H = \frac{2 \pi}{10} \frac{h I}{\lambda d}$$

Using the subscript s to indicate that it is the sending rather than the receiving antenna which is considered,

$$H = \frac{2 \pi}{10} \frac{h_s I_s}{\lambda d} \tag{8}$$

This derivation follows the conceptions presented in the early pages of Lorentz, "The Theory of Electrons". It is equivalent to Hertz's intricate proof, but is more direct. The way in which the result is expressed here accords more closely with the physical ideas and with actual practise, being expressed in terms of current rather than electric charge, since it is current that is actually measured in an antenna and the current furthermore is generally uniform in the vertical portion of the antenna.

Formula (8) gives the radiated magnetic field from a sending antenna at a distance *d* along the earth's surface. The units are the gilbert per cm. for *H*, the ampere for *I*, and the centimeter for all lengths, as previously stated.

Undamped alternating current in the antenna was assumed. The same result, however, is obtained if the current is damped. At very great distances from the sending aerial, the magnetic field is less than that calculated by formula (8), because of absorption of the power of the wave as it travels along. This may be taken into account by multiplying the right-hand member of (8) by a correction factor F_1. The value of this factor for daytime transmission over the ocean, derived from the experiments of L. W. Austin, Scientific Paper of the *Bureau of Standards No.* 159; 1911, is

$$F_1 = \epsilon^{-0.000047\, d/\sqrt{\lambda}} \tag{9}$$

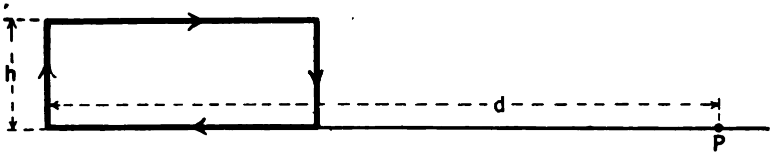

Fig. 4—Calculation of Magnetic Field Radiated from a Coil

for *d* and λ both in meters. This correction ordinarily needs to be applied only when the distance is greater than 100 kilometers.

2. Radiation from a Coil

It was formerly the belief that a coil could not radiate, because the current up one side of the coil (Fig. 4) produces a field equal and opposite to that down the other side of the coil. This is erroneous because the two equal fields are not exactly opposite. The phase between the two departs from 180 deg. because of the finite time required for the field to be propagated from one side of the coil to the other. It is only along the axis of the coil that the calculated radiation is zero. The actual resultant field radiated from the coil may be deduced in either of two very simple ways, both of which are interesting from the physical standpoint. The first deals with the instantaneous values of the magnetic field, and the second with the effective values.

The following additional symbols are used:

l = horizontal length of coil aerial.

N = number of turns of wire of coil aerial.

θ = phase angle between values of field intensity a distance l apart in the wave.

First Deduction. Consider a rectangular coil of height h and horizontal length l. The magnetic field at a point P in the d direction is the resultant of the fields arising from current in the two vertical sides of the coil, the horizontal sides contributing nothing. The magnetic field at P due to any one of the vertical wires of the coil is calculated from equation (**5**) above. Neglecting the second terms, because d is large, the instantaneous values of the magnetic field (Fig. 4) at the distance d and $(d - l)$ respectively from the two vertical sides are

$$H_d = -\frac{h\,N\,\omega\,I_0}{10\,c\,d} \cos\omega\,(t - d/c)$$

$$H_{d-l} = +\frac{h\,N\,\omega\,I_0}{10\,c\,(d-l)} \cos\omega\left(t - \frac{d-l}{c}\right)$$

The resultant field H_t is the algebraic sum of these two, which becomes since $(d - l)$ is very nearly d when d is large,

$$H_t = -\frac{h\,N\,\omega\,I_0}{10\,c\,d}\,2\sin\omega\left(t - \frac{d - l/2}{c}\right)\sin\frac{\omega\,l}{2\,c}$$

The effective value of the resultant field is

$$H = \frac{2}{10}\,\frac{h\,N\,\omega\,I}{c\,d}\,\sin\frac{\omega\,l}{2\,c}$$

Using the relations

$$\frac{\omega}{c} = \frac{2\,\pi}{\lambda}$$

and $\sin\frac{\omega\,l}{2\,c} = \frac{\omega\,l}{2\,c}$,

the latter holding when the angle is small, *i. e.*, l small compared with the wave length,

$$H = \frac{4\,\pi^2}{10}\,\frac{h_s\,l_s\,N_s\,I_s}{\lambda^2\,d} \qquad (\mathbf{10})$$

This is the radiated magnetic field from a sending coil aerial at a distance *d* along the earth's surface, the direction of *d* being in the plane of the coil. The units are international units as stated under equation (**8**). The deduction assumes that the ground below the coil is not so good a conductor as to form an image of the coil. Thus the formula applies to a radiating coil in an airplane as well as to one at a ground or ship station.

The formula applies for either damped or undamped current I_s in the sending antenna. For very great distances the right-hand side of the formula must be multiplied by the distance correction factor F_1 given in (9), the same as for a radiating antenna.

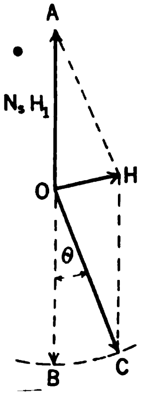

Fig. 5 — Phase Relations of Magnetic Fields Radiated from a Coil

Second Deduction. The radiated magnetic field due to one of the sides of the coil is $N_s H_1$, and from formula (**8**),

$$H_1 = \frac{2\pi}{10} \frac{h_s I_s}{\lambda d} \tag{11}$$

If the two vertical sides of the coil coincide, their magnetic fields would be equal and opposite, as shown by the lines *O A* and *O B*, Fig. 5. But since the two vertical sides are separated by the distance *l*, at any instant the field at *P* (Fig. 4) from the left side of the coil has traveled a distance *l* farther than the field from the right side. If then $N_s H_1$ is the field at *P* due to the right side, the field at *P* due to the left side is shifted in phase from the position *O B* to *O C* in Fig. 5, where the angle θ between them is the phase angle between the values of the field a distance *l* apart in the wave.

The distance *l* is the same fraction of the wave length that the angle θ is of a complete cycle, 2π. That is,

$$\frac{\theta}{2\pi} = l_s/\lambda$$

or

$$\theta = 2\pi\, l/\lambda \tag{12}$$

The resultant of *O A* and *O C* is their vector sum,

$$H = N_s H_1 \sqrt{2\,(1 - \cos\theta)} \tag{13}$$

When θ is small, *i. e.*, l small compared with the wave length,

$$\frac{H}{N_s H_1} = \sin \theta = \theta$$

$$\therefore H = N_s H_1 \theta \tag{14}$$

Thus the radiated magnetic field from a coil is equal to the field from one side of the coil multiplied by the phase angle θ corresponding to the distance l between the sides of the coil.

From (**14**) and (**11**),

$$H = \frac{2\pi}{10} \frac{h_s N_s I_s}{\lambda d} \theta \tag{15}$$

This equation, together with (**12**), gives identically formula (**10**) obtained by the first deduction.

It was assumed in these deductions that the current was uniform throughout the coil. If the distributed capacity of the coil is appreciable the current in the coil will be different at different points. Thus the current in the middle may be greater than at the ends. This also may give rise to radiation from the coil, but is an entirely separate phenomenon from the phase angle between the two sides of the coil which has been discussed. This question of distributed capacity requires consideration particularly when coils are used having dimensions comparable with the wave length. The phenomenon is discussed further under "Antenna Effect" in Sec. VI 3 below.

3. RECEIVED CURRENT IN AN ANTENNA

The current flowing in the receiving aerial circuit when the field intensity of the wave traversing the aerial is known can be calculated in several ways. An electromagnetic wave in space has both an electric and a magnetic field intensity which are at right angles to each other and to the direction of propagation of the wave. The two field intensities are related to each other by

$$\mathcal{E} = 300. H \tag{16}$$

where $\mathcal{E}$ is in volts per cm. and H in gilberts per cm.

The following additional symbols are used in this and the following section:

$\mathcal{E}$ = electric field intensity
E = electromotive force in receiving aerial
R = resistance of receiving aerial circuit
ϕ = magnetic flux

First Deduction. The electromotive force, and thence the current produced in an antenna may be calculated from the principle that relative motion of a magnetic field and a conductor create an electromotive force in the conductor whose value is

$$E = 10^{-8}\, h_r\, Hc \tag{17}$$

when the directions of the field, the motion, and the conductor are mutually perpendicular, h_r being the length of the conductor and c the velocity of the relative motion. This then gives the e. m. f. in an antenna of height h_r, produced by electromagnetic wave having magnetic field intensity H and travelling with the velocity of c.

In ordinary practise, the reactance in series with the antenna is varied to produce resonance to the frequency of the incoming wave, so that

$$I_r = \frac{E}{R} \tag{18}$$

Inserting for c its value, 3×10^{10} in equation (**17**).

$$I_r = 300 \,.\, \frac{h_r\, H}{R} \tag{19}$$

This is the current in amperes received in a flat-top antenna using the centimeter as the unit of length, with resistance of circuit in ohms, and the magnetic field intensity in gilberts per cm.

The received current is less than that given by the formula if the wave is damped, since an undamped alternating field was assumed in the discussion. For a damped field the e.m. f. acting on the aerial is similarly damped and equation (**18**) does not hold. Correct results are obtained by multiplying the right-hand side of formula (**19**) by the correction factor F_2 obtained as follows:

If the magnetic field intensity and hence the e. m. f. has the decrement δ', the effective current is not I_r, defined by (**18**), but another value which we shall call I_ρ. The value of I_s may be found by the aid of the generalized definition of decrement given in the author's paper, "The Measurement of Radio-Frequency Resistance, Phase Difference, and Decrement", *Proc. I. R. E.*, 7, p. 27; Feb. 1919.

For decrements smaller than about 0.2, the logarithmic decrement is one-half the ratio of the average energy dissipated per cycle to the average energy associated with the current at the maximum of the cycle.

Taking the average power as E^2/R, the average energy dissipated per cycle $= \frac{E^2}{f R}$. The average energy associated with the current at the maximum of each cycle $= L I_p^2$. The energy-ratio definition of decrement just given applies to the sum of the decrements acting, *viz.*, the decrement δ' of the e. m. f. and the decrement δ of the aerial circuit. The value of δ is $\frac{R}{2 f L}$. Applying the decrement definition

$$\delta' + \delta = \frac{\frac{E^2}{f R}}{2 L I_p^2}$$

$$= \frac{E^2 R}{2 f L R^3 I_p^2}$$

$$= \frac{E^2 \delta}{R^2 I_p^2}$$

$$I_p^2 = \frac{E^2}{R^2} \frac{\delta}{\delta' + \delta}$$

From the relation, $E^2/R^2 = I_r^2$,

$$I_p = I_r \sqrt{\frac{\delta}{\delta' + \delta}} = I_r \sqrt{\frac{1}{1 + \frac{600. \mathrm{L} \, \delta'}{R \lambda}}}$$

where L is in microhenries and λ is in meters.

This reduces to $I_p = I_r$ when δ' is small compared with δ. Thus in the particular case of an undamped wave, where $\delta' = 0$, no correction is needed.

Correct results are obtained from equation (**19**) for any damped wave by multiplying its right-hand member by the correction factor F_2, given by

$$F_2 = \sqrt{\frac{1}{1 + \frac{600 \; . L \, \delta'}{R \lambda}}} \qquad \textbf{(20)}$$

where L is the inductance of the receiving aerial circuit in microhenries and λ is wave length in meters, and δ' is the logarithmic decrement of the damped wave that is being received.

Second Deduction. The same formula may be derived from entirely independent consideration of the electric field associated with the wave. The e. m. f. between two points in space is the product of the distance between them by the electric field intensity along the line joining them. Thus the e. m. f. produced in a flat-top antenna is $\mathcal{E}$ times the height, the direction of $\mathcal{E}$ being assumed to be vertical.

$$E = h_r \mathcal{E} \tag{21}$$

Inserting the value of $\mathcal{E}$ from (**16**) and dividing by the resistance,

$$I_r = 300 \cdot \frac{h_r H}{R} \tag{22}$$

This is identically the same formula obtained above from consideration of the magnetic field.

4. RECEIVED CURRENT IN A COIL

The current in a receiving coil aerial can be calculated in a number of different ways, all very simple and all giving the same result. The first conception which will be presented is simply that an e. m. f. is produced in the circuit by the time variation of magnetic flux through it.

The other modes of calculation involve the phase angle between the two vertical sides of the coil. The e. m. fs. acting in the two vertical sides are exactly equal and oppose each other in producing a current around the circuit when the plane of the coil is perpendicular to the direction of propagation of the wave. When the coil is turned in any other direction, however, the e. m. fs. in the two sides are not exactly opposite in phase because of the difference in time required for the field to be propagated to one side of the coil and to the other. The e. m. f. can be calculated either from the electric or the magnetic field, as in the discussion of received current in an antenna. The resultant e. m. f. can be found either from the algebraic sum of the instantaneous e. m. fs. in the two vertical sides or the vector sum of the effective e. m. fs. These two methods are used in the second and third deductions respectively, below.

The phase angle between the two sides of the coil is a very different thing from the phenomenon caused by the distributed capacity of the coil. It is assumed in the deductions given here that the current is uniform in all parts of the coil, which is not true when the distributed capacity is appreciable. Such capacity is large in coils of dimensions comparable with the wave length, and in such cases consideration must be given to the separate and additional phenomenon of distributed capacity.

First Deduction. Assuming that the dimensions of the coil are small compared with the wave length, the magnetic field intensity is practically uniform throughout the coil. When the plane of the coil is parallel to the direction of propagation of the wave, the e. m. f. induced in the coil is

$$E = 10^{-8}\,\omega\,\phi$$

$$\text{Now, } \phi = \mu\, h_r\, l_r\, N_r\, H$$

Since the permeability $\mu = 1$, and $I_r = E/R$ because in ordinary practise the condenser in series with the coil is adjusted to produce resonance with the frequency of the incoming wave,

$$I_r = 10^{-8}\,\frac{\omega\,\phi}{R} = 10^{-8}\,\frac{\omega\, h_r\, l_r\, N_r\, H}{R}$$

$$= 2\,\pi\, c\, 10^{-8}\,\frac{h_r\, l_r\, N_r\, H}{R\,\lambda}$$

$$I_r = 600\,.\,\pi\,\frac{h_r\, l_r\, N_r\, H}{R\,\lambda} \qquad \textbf{(23)}$$

This is the current received in a rectangular coil aerial of N turns, with its plane parallel to the propagation of the wave. The units are international units as stated under formula (**19**). No image is assumed in the ground, so the formula applies not only to a receiving coil at a ground or ship station but also to an airplane direction finder. The heights at which airplanes fly are such that the field of the wave is usually not much different from its value at the ground.

There are two correction factors that may need to be applied to this formula, both of which make the result smaller. If the wave is damped, the right-hand side of the formula should be multiplied by the decrement correction factor F_2, given by (**20**), the same as for a receiving antenna.

When the plane of coil is in some direction other than parallel to the direction of propagation of the wave, the right-hand side of formula (**23**) must be multiplied by the direction correction factor F_3 given by

$$F_3 = \cos \alpha \tag{24}$$

where α is the angle between the direction of propagation of the wave and the plane of the coil.

Second Deduction. The e. m. f. produced in any one of the vertical wires of the coil is given by either equation (**17**) or (**21**) above, deduced from considerations of the action of the magnetic and the electric field intensity, respectively. Each of these equations reduces to

$$E_1 = 300 .\, h_r H \tag{25}$$

The instantaneous e. m. f. in either of the two vertical sides of the coil is therefore

$$e' = 300\, h_r N_r H_0 \cos \omega t$$

The instantaneous e. m. f. in the other side of the coil is produced by the magnetic field existing in the wave a distance l away, when the plane of the coil is parallel to the direction of propagation of the wave. This e. m. f., e'', has the same direction in space but the opposite direction as far as producing current around the circuit is concerned.

$$e'' = -300 \;.\, h_r N_r H_0 \cos (t - l/c)$$

The resultant e. m. f. in the circuit is the algebraic sum of these two,

$$e = 300 \;.\, h_r N_r H_0\, 2 \sin \omega \left(t - \frac{l}{2c} \right) \sin \frac{\omega l}{2c}$$

The effective value of the resultant e. m. f. is

$$E = 600 \;.\, h_r N_r H \sin \frac{\omega l}{2c}$$

Since when the angle is small, *i. e.*, l small compared with the wave length,

$$\sin \frac{\omega l}{2c} = \frac{\omega l}{2c} = \pi \frac{l}{\lambda}$$

$$E = 600 \;.\, \pi \frac{H_r l_r N_r H}{\lambda} \tag{26}$$

Dividing by R, this gives the identical value of I_r obtained in (**23**) by the first mode of deduction.

Third Deduction. The e. m. f. produced in one of the sides of the coil is $N_r E_1$, where from either equation (**17**) or (**21**) above, *i. e.*, from consideration of either the magnetic or the electric field intensity, respectively,

$$E_1 = 300 \; . h_r H \qquad (\mathbf{25})$$

If the two vertical sides of the coil coincided, the e. m. fs. produced in them would be equal and exactly neutralize each other, as shown by the lines $O\,A$ and $O\,B$, Fig. 6. But since the two vertical sides are separated by the distance l, at any instant the field acting on one side of the coil has traveled a distance l farther than that acting on the other side. If then $N_r E_1$ is the e. m. f. in one side of the coil, the e. m. f. in the other side is shifted in phase from the position $O\,B$ to the position $O\,C$ in Fig. 6, where the angle θ between them is the phase angle between the values of the field a distance l apart in the wave.

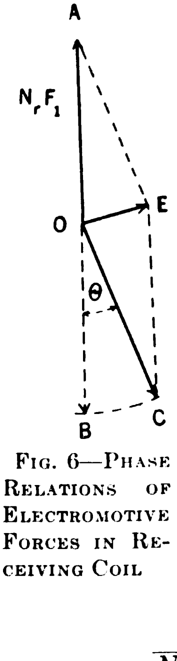

Fig. 6—Phase Relations of Electromotive Forces in Receiving Coil

The distance l is the same fraction of the wave length that the angle θ is of a complete cycle, $2\,\pi$, *i. e.*,

$$\frac{\theta}{2\,\pi} = \frac{l\,r}{\lambda} \qquad (\mathbf{27})$$

The resultant of $O\,A$ and $O\,C$ is their vector sum

$$E = N_r E_1 \sqrt{2\,(1 - \cos\theta)} \qquad (\mathbf{28})$$

When θ is small, *i. e.*, l small compared with λ

$$\frac{E}{N_r E_1} = \sin\theta = \theta$$

$$\therefore E = N_r E_1 \,\theta \qquad (\mathbf{29})$$

From (**25**),

$$E = 300\, h_r N_r H\, \theta \qquad (\mathbf{30})$$

Thus the e. m. f. acting in the coil is equal to the e. m. f. in one side of the coil multiplied by the phase angle θ corresponding to the distance l between the sides of the coil.

Equations (**27**) and (**30**) combined give (**26**) and by dividing by R formula (**23**) is obtained.

III. DISCUSSION OF THEORY OF RADIATION AND RECEPTION

1. Distinction between Induction and Radiation

Certain fallacies which have appeared in text-books and discussions arise from insufficient understanding of the difference between an induction field and a radiation field. Such fallacies are:

a. An "open" circuit can radiate, while a "closed" circuit can not.

b. There is no radiation from a circuit at low frequencies.

c. Induction and radiation are the same phenomenon.

d. The action of an antenna differs from that of a coil aerial in that the former is due to electrostatic fields and the latter to magnetic fields.

These fallacies will now be discussed. Fallacy *c* has led to the supposition that the radiation and reception of electric waves can be taught in terms of transformer action. It should not be difficult to separate the two ideas, for there is a definite and clear distinction between the field due to induction and that due to radiation. The total magnetic field at a distance *d* from a radiating antenna is, from equation (**5**)

$$H = \frac{2\pi}{10}\frac{h_s I_s}{\lambda d} + \frac{j}{10}\frac{h_s I_s}{d^2} \tag{31}$$

where j indicates that the two terms differ in phase by 90 deg. The first term represents the radiation field and the second term the induction field. The fact that one contains λd in the denominator while the other contains d^2 makes them radically different in nature. This gives the mathematical distinction between induction and radiation. The physical difference is discussed in Sec. 3 below.

The radiation field becomes relatively more important than the induction field as the distance d is increased or as the wave length is diminished (*i. e.*, the frequency increased). The question whether radiation or induction predominates in any given case can be settled by calculation from the formula. Thus, the two fields are equal at a distance

$$d = \frac{\lambda}{2\pi}$$

For points closer to the antenna than this the induction field predominates. For points farther away, the radiation field predominates and the induction field falls off rapidly with distance and becomes negligible.

Certain early experiments in wireless signalling used true induction, *e. g.*, the induction telegraphy of Preece and of Dolbear. When higher frequencies were used by later experimenters, signals of appreciable strength were received at distances of several wave lengths. These were genuine radiation signals, now commonly called radio.

2. IS RADIATION LIMITED TO HIGH FREQUENCIES?

The answer to this should be obvious from formulas (**8**) and (**10**). The radiated field does not become zero, no matter how great λ is. For alternating current of any frequency, no matter how low, radiation takes place from the circuit. To be sure, the radiation is greater the higher the frequency, so that high-frequency circuits are better radiators than low-frequency ones, and this is all the basis there is for the mistaken idea that only high-frequency circuits radiate.

This applies to radiation from a coil as well as from an antenna. It has sometimes been stated that a coil will not radiate, the statement being put in the form that only "open" circuits radiate. The statement is doubly faulty since electricity can flow only in closed circuits. The meaning intended by "open" circuit is a circuit containing a condenser of open form, that is, with two plates well separated. There are two misconceptions at the base of the belief that a "closed" circuit or one not containing a condenser would not radiate. In the first place, some have doubtless thought that waves would be started in the ether only by an electrostatic disturbance and thus could not be produced by a metallically closed circuit. Or, supposing it was understood that a magnetic disturbance in the ether would send out a wave just as readily as an electrostatic disturbance, it may have been thought that the radiation from one side of the circuit would be neutralized from that from the opposite side. As has already been shown in this paper, the two disturbances do not exactly neutralize each other, on account of the finite time of propagation from one side of the circuit to the other, and the resultant is what gives rise to the radiation from a metallically closed circuit.

3. EQUIVALENCE OF ELECTROSTATIC AND MAGNETIC FIELDS IN A WAVE

The physical distinctions between radiation and induction are: (a) the latter is fixed in space and the former moves through space with the velocity of light, and (b) in the case of radiation the magnetic field is always accompanied by an electrostatic field of value

$$\mathcal{E} = 300 \ . H \qquad (16)$$

and vice versa, whereas in the case of induction there is no fixed relation. It is, of course, true that whenever magnetic induction varies an electrostatic field is produced, and similarly whenever electrostatic induction varies a magnetic field is produced. But it is only in a radiated wave that these variations take place in such a way that one can be calculated from the other by the fixed relation (**16**). When there is a fixed electrostatic field associated with a circuit which does not vary, the magnetic field associated with this electrostatic field is zero, and vice versa.

In a radiated wave, then, the electrostatic and magnetic field are no longer independent phenomena but are strictly equivalent. Indeed, they are but two aspects of the same thing. Perhaps this will be clearer from the analogy of a sound wave. In a mechanical apparatus, elastic action and inertia act independently in various parts of the apparatus. In a sound wave, however, the effects of elastic action and inertia are mutual parts of a single phenomenon, the sound wave.

In considering any effect of the electromagnetic wave, it is equally permissible to consider the electrostatic or the magnetic field associated with the wave. They are equivalent and lead to the same result. This has been amply demonstrated above in this paper. The current received in an antenna, calculated from the electrostatic field, was exactly the same as calculated from the magnetic field. The same agreement was found for the coil aerial. This disposes of the question whether the current produced in an antenna or a coil aerial is caused by the electrostatic or the magnetic field present in the wave, or both.

Complete discussions of electromagnetic waves are given in such treatises as Maxwell, "Electricity and Magnetism", 1873; Jeans, "Electricity and Magnetism", 1907; Lorentz, "The Theory of Electrons", 1909.

4. WHAT RADIATION IS

It has been shown that radiation differs from induction by a definitely calculable amount, that either kind of circuit radiates at any frequency, that there are both an electrostatic and a magnetic field present in every wave, having a constant ratio, and that any effect of the wave may be considered as due either to the electrostatic or the magnetic field of the wave.

Radiation is the moving disturbance of the ether, the energy associated with which does not return to the radiator.

This conception leads to more correct ideas than are current on the mechanism of radiation from an antenna; and permits explanation of the radiation from a coil aerial, which is not covered at all by the usual explanations of radiation in text-books. Such explanations have led to the impression that the radiation largely depends on the form of the electrostatic lines of force which are present at the edges of the radiator. It might thus be supposed that in a flat-top antenna or a condenser aerial the current in the central portions of the condenser was not effective in causing radiation while only that which spread into the surrounding space from the edges was effective. This appears incorrect. If it were correct, the builders of long flat-top antennas must have wasted a great deal of wire. All of the dielectric current sends a moving disturbance out into the ether. The portion of the energy associated with this disturbance that does not return to the radiator is that connected with the first term of equation (**31**). In this term the total antenna current appears. The radiation is the moving disturbance caused by the whole of the current which the antenna makes flow in the dielectric.

The ordinary treatment of the mechanism of radiation from an antenna is misleading also because it deals with radiation at the fundamental wave length. In practise, antennas are usually loaded. The radiation depends to no degree whatsoever on the value or location of any of the field lines attached to the aerial, but only on the variation of the lines. And *all* the lines when varying give rise to radiation. Thus the stationary field is given by the second term of formula (**31**), the first is the radiation term, and they are independent.

IV. COMPARISON FORMULAS

1. Derivation from Theoretical Formulas

Formulas are here derived to answer the practical question of how far a given coil will send or receive in comparison with a given antenna. The formulas also answer such questions as the length of a coil aerial required to give a particular ratio of performance of coil and antenna.

The ratio of the magnetic field radiated from a current coil to that from an antenna, for a given sending current, distance, wave length, and height, is obtained from equation (**13**). The ratio of the distance from a coil to that from an antenna, at which a given magnetic field is produced, is the same as the ratio of the magnetic field produced by a coil to that produced by an antenna at a given distance. Either ratio is therefore given by the following expression, which assumes the same current I_s, wave length λ, and height h_s, for the coil and the antenna,

$$d_c/d_a = N_s \sqrt{2\,(1 - \cos\theta)}$$

Inserting the value of θ and neglecting the subscript s,

$$d_c/d_a = N \sqrt{2\,(1 - \cos 2\,\pi\, l/\lambda)} \qquad (\mathbf{32})$$

When the length of the coil l is small compared to λ (*i. e.*, for most practical purposes, less than $0.1\,\lambda$), this simplifies to

$$d_c/d_a = 6.28\, N\, l/\lambda \qquad (\mathbf{33})$$

This could have been deduced directly from (**8**) and (**10**). The expression is similarly deduced for comparison of the distances obtained with a coil and an antenna of different heights,

$$d_c/d_a = 6.28\, N\, l/\lambda\ h_c/h_a \qquad (\mathbf{34})$$

The length of a coil required to give a particular ratio of performance to an antenna is given by solving these formulas for l. From (**32**),

$$l = \frac{\lambda}{2\,\pi} \cos^{-1}\left(1 - \frac{1}{2\,N^2}\left[\frac{d_c}{d_a}\right]^2\right) \qquad (\mathbf{35})$$

When the length of the coil is small compared to λ, the simpler formula suffices,

$$l = 0.16\, \lambda/N\ d_c/d_a \qquad (\mathbf{36})$$

The relative distances at which an antenna or a coil will receive a given wave are given by the same identical expressions that have just been deduced for sending aerials. Thus formula (**32**) may be deduced from (**28**) and (**33**) from (**19**) and (**23**). They give the ratio of the distance from the source at which a given e. m. f. will be produced in a coil aerial to that in an antenna, assuming the same height h_r and wave length λ for the coil and the antenna. They also give the ratio of the e. m. f. produced in a coil to that in an antenna for a given value of magnetic field intensity, or the ratio of currents when the resistances and other quantities are the same in coil and antenna. Equations (**34**), (**35**), and (**36**) similarly hold for receiving as well as sending aerials. For comparison of current in a coil and an antenna of different resistances as well as different heights

$$d_c/d_a = 6.28\, N\, l/\lambda \quad h_c/h_a \quad R_a/R_c \tag{37}$$

The relative distance of transmission between two coil aerials and between two antennas, for a given sending current, is similarly found from equations (**8**), (**10**), (**19**), and (**23**). The ratio of received current for coils and antennas the same distance apart is given by the same formula, which assumes the same sending current I_s and wave length λ for the pair of coils as for the pair of antennas.

$$\frac{d_{cc}}{d_{aa}} = 39.5\, \frac{l_s\, l_r\, N_s\, N_r}{\lambda^2} \quad \frac{(h_s\, h_r)\, c}{(h_s\, h_r)\, a} \quad \frac{R_a}{R_c} \tag{38}$$

All of these formulas assume that the decrement correction factor F_2 is the same for coil and antenna in all cases. If waves of different decrement are used, apply the factor F_2 as stated in connection with (**20**). If the plane of the coil considered is not parallel to the direction of propagation of the wave, apply the factor, cos α, as stated in connection with (**24**).

2. Examples of Comparison of Coil and Antenna

What is the length of the coil, either as sender or receiver, equivalent to an antenna of the same height? The answer is given by (**36**). For $d_c/d_a = 1$,

$$l = 0.16\ \lambda/N \tag{39}$$

This is the correct length except for a single-turn coil. Then $N = 1$ the more exact formula (**35**) must be used. This gives, for the equivalent coil,

$$l = 1/6\ \lambda$$

Thus a single-turn coil of length 1/6 the wave length is equivalent to an antenna of the same height. For a coil of 8 turns, however, the length of the coil equivalent to an antenna of the same height is, from (**39**), 0.02 of the wave length.

When the length of the coil is small compared with the wave length, *i. e.*, as already stated, l less than about 0.1 λ, the performance ratio is given by (**33**). For a length greater than 0.1 λ, however, the more accurate formula (**32**) must be used.

Thus, when the length is exactly a sixth of a wave length, from (**32**),

$$d_c/d_a = N$$

Thus any coil of length 1/6 the wave length is equivalent to an antenna of N times the height of the coil. When the length of the coil is a quarter wave length, similarly

$$d_c/d_a = \sqrt{2}\,N$$

For a coil of length equal to half the wave length,

$$d_c/d_a = 2\,N$$

This is the maximum or best performance for a coil aerial. If the length is increased beyond a half wave length, the performance ratio decreases, and at $l = \lambda$ it is equal to O just the same as for $l = O$.

These values of the performance ratio of a coil aerial are obvious from Fig. 5 or 6.

These comparisons all apply to either transmitting or receiving aerials. They assume, however, in the case of a transmitting antenna or coil, that the same current flows; and, when applied to receiving aerials, that the resistance is the same in either coil or antenna. As a matter of fact, however, it is easy to secure a considerably lower resistance in a coil aerial circuit than in an antenna circuit. This is taken account of by the factor R_a/R_c as in (**37**) and (**38**). The difference in current in a transmitting coil and antenna is taken account of by multiplying the right-hand members of (**32**) and (**33**) by the ratio of the sending currents I_c/I_a. On this account a coil is sometimes a more effective radiating or receiving device than an antenna of considerably greater dimensions.

The comparison formulas and conclusions drawn from them are subject to the same errors as the transmission formulas, as discussed in Sec. V 2 below.

3. THE CONDENSER AERIAL

Since the dimensions of a coil aerial which would give the same performance as a given antenna are a length equal to $\frac{0.16}{N}$ times the wave length and a height equal to the antenna height, rather large structures are required. For example, a flat-top antenna 30 meters above the ground operating on a 600-meter wave is equivalent to a four-turn coil 24 meters long by 30 meters high. The dimensions of the equivalent coil are thus of the same order as the dimensions of the antenna.

It is possible to escape from the apparent necessity of large structures for effective radio transmission and reception in two ways. First, the coil aerial can easily be made to have a lower resistance than the antennas ordinarily used, and its size reduced in proportion to the reduction of resistance. This is mainly because the condenser used in the coil aerial circuit can be one having practically no resistance while the condenser consisting of antenna and ground has a large resistance. Thus by due attention to the minimizing of resistance in its circuit, the coil aerial may be of small dimensions and yet highly effective. The size may, of course, be reduced also in proportion as the number of turns is increased.

It is equally possible to avoid an aerial of large dimensions without having recourse to a coil aerial. The alternative is to use the antenna principle, but use a special construction of much lower height. At first sight it would appear that this would make a poorer antenna, since the effectiveness is proportional to the height, according to either (**8**) or (**19**). And this is true if the antenna is merely lowered a moderate amount. Such lowering increases the capacity only very slightly, not nearly in proportion to the decrease in height. In order to secure an appreciable gain it is necessary to have the height very small and use a special construction to reduce the resistance as much as possible. A good method is to replace the ordinary antenna-ground structure in which the antenna is one plate of a condenser and the ground the other plate, by an aerial consisting of two horizontal metal condenser plates. This may be called a "condenser aerial". The formulas derived for antennas apply to it.

Such an aerial has lower conductor resistance than the ordinary antenna, and since it has greater capacity a small inductance will be used in series with it which will also have smaller resistance and thus reduce the resistance of the circuit. Furthermore, the resistance of an antenna largely arises from the imperfect dielectrics, such as vegetation, buildings, and poor insulators, present in its field (as shown in Scientific Paper of the *Bureau of Standards* No. 269, by J. M. Miller), and the resistance from the grounding wires to ground. These can be eliminated in a condenser aerial. Finally, then, the resistance of the aerial circuit can be reduced to more than compensate for the reduction in height. This will result in a larger current I_r in formula (**19**), or in a larger H in formula (**8**) because of the increase of the sending current.

The advantage of the very low antenna has been observed in the experiments of the Kiebitz and others on so-called earth antennas. It is probable that still greater advantages would be obtained by the condenser aerial as here described. The special construction required to eliminate dielectric loss would involve making the lower plate considerably wider and longer than the upper plate, or else having both plates a considerable distance above the ground, and keeping the space between the plates free from poor dielectrics. An aerial consisting of a pair of metal plates elevated from the ground was used described by Oliver Lodge in 1897, and again by Lodge and Muirhead in *Proc. Royal Soc.*, 82, p. 227; 1909, who found that it worked best without being grounded. The author is informed that the same sort of an aerial has recently been tried on airplanes, using the upper and lower planes as the condenser plates. Such an aerial would be ideal for airplanes if the space between could be kept free from poor dielectrics. If the plates of the condenser aerial have their length and width approximately equal, the aerial radiates in all directions. If a long narrow condenser is used it would probably be very directional, both as a transmitting and receiving device. Such a condenser might consist of a pair of parallel wires, which would be a considerable improvement on the ground antenna.

An example will make clear how the size of the condenser aerial compares with other aerials. It was found above that antenna 30 meters high was equivalent to a four-turn coil 24 meters long by 30 meters high, both operating on a 600-meter wave and with circuits of the same resistance. For the same wave length and with an inductance of 100 microhenries, in series, the capacity of a condenser aerial would need to be 0.00102 microfarad, which would be given by a pair of square plates 1 meter apart and 10.7 meters on a side. The height is thus reduced in the ratio of about 25 to 1, and the horizontal dimensions 3 to 1 in comparison with the coil aerial.

The aerial can be made as small as desired. If a given coil is to be used in series, the capacity of the aerial is maintained constant by reducing the distance between the plates when the area of the plate is reduced. The author made some interesting experiments with a small condenser aerial as a receiving device, used inside the laboratory with no ground connection. The plates consisted of copper netting. The top plate was 250 cm. square and the distance between them was 15 cm. The signals received, with either a crystal detector or electron tube, were roughly of the same intensity as those received with a simple coil aerial of the type and size ordinarily used as a direction finder.

The indication of absolute direction of propagation of the waves as well as line of propagation which has been developed by French and other workers, using combinations of ordinary antenna and coil aerials was observed in the experiments on the condenser aerial. An inductance coil of rather large dimensions used in series with the condenser acted as a receiving aerial. As this coil was rotated, the signal varied from maximum in one angular position to zero in a position 180 deg. from the first, instead of 90 deg. as occurs when a coil aerial is used independently of any antenna action. Apparently the action of the condenser aerial reinforced that of the coil in one position and neutralized it in the opposite position. When the connections to the coil were interchanged, the effect shifted 180 deg. Reversing the connections of the coil reverses the e. m. f. in the coil, *E*, in Fig. 6, just as a reversal of the direction of the wave would do, whereas the direction of the e. m. f. in the antenna or condenser aerial is unchanged. The reason why the condenser e. m. f. can neutralize the coil e. m. f. is probably that the capacity of the coil introduces different values of reactance to the two e. m. fs. Thus, when the circuit is tuned for one of these e. m. fs. the currents due to the two differ 90 deg. in phase. This phase angle may be shifted 180 deg. by a very slight variation of the reactance of the circuit. Because of this, systems for determining the absolute direction of radio waves require very delicate adjustment.

The ordinary laboratory type of condenser used in radio circuits does not function as a condenser aerial. This is because the interleaving of the plates results in the current in each portion of the dielectric being balanced by the current in a neighboring portion. This is discussed further below in Sec. VI 3 and illustrated in Fig. 17.

V. TRANSMISSION FORMULAS

1. Statement of Formulas

The current received in any aerial may be calculated in terms of the current in any transmitting aerial, either antenna or coil by the following four formulas. They are derived by combining equations (**8**), (**10**), (**19**), and (**23**). The symbols are as previously given, also stated in the Appendix below.

Antenna to antenna:

$$I_r = \frac{188 \;.\, h_s\, h_r\, I_s}{R\, \lambda\, d} \tag{40}$$

Antenna to coil:

$$I_r = \frac{1184 \;.\, h_s\, h_r\, l_r\, N_r\, I_s}{R\, \lambda^2\, d} \tag{41}$$

Coil to antenna:

$$I_r = \frac{1184 \;.\, h_s\, l_s\, h_r\, N_s\, I_s}{R\, \lambda^2\, d} \tag{42}$$

Coil to coil:

$$I_r = \frac{7450 \;.\, h_s\, l_s\, h_r\, l_r\, N_s\, N_r\, I_s}{R\, \lambda^3\, d} \tag{43}$$

Formulas such as (**40**) have existed heretofore. The formulas here given generalize the antenna-to-antenna formula, so that calculations can be made for any kinds of aerials.

The lengths in these formulas may be in any units, provided the same unit is used for all the lengths. The meter is usually the most convenient unit. If the heights and wave length are in meters and the distance d in miles, the four constants in the four formulas become respectively:

0.117
0.736
0.736
4.63

To calculate the distance at which a given current will be received, as when a particular receiving arrangement is specified, the formulas may be stated explicitly for d. I_r and d are interchanged in each formula. For example, the formula for antenna-to-coil (**41**) becomes

$$d = \frac{1184 \;.\, h_s\, h_r\, l_r\, N_r\, I_s}{R\, \lambda^2\, I_r} \tag{44}$$

All of these transmission formulas are for daytime transmission. Greater values are obtained at night, probably because the waves are reinforced by reflection form ionized layers of the upper atmosphere, which are broken up by sunlight in the daytime. The formulas are all subject to correction factors for distance and for decrement. If the distance is very great (in ordinary cases, over 100 kilometers), the right-hand side of the formula should be multiplied by the correction factor F_1. The value given below for F_1 is for transmission over sea water. Its value for transmission over land would be greater. If damped waves are used, the correction factor F_2 should be similarly applied. Furthermore, if the plane of the receiving coil is not parallel to the direction of propagagtion of the wave, the correction factor F_3 must be similarly applied to formulas (**41**) and (**43**) and related formulas such as (**44**). In formulas (**42**) and (**43**) the direction of the wave is taken to be that of the plane of the transmitting coil. The three correction factors are:

$$F_1 = \epsilon^{-0.000047\, d/\sqrt{\lambda}} \qquad \textbf{(9)}$$

$$F_2 = \sqrt{\frac{1}{1 + \frac{600\ .\, L\,\delta'}{R\,\lambda}}} \qquad \textbf{(20)}$$

$$F_3 = \cos\alpha \qquad \textbf{(24)}$$

All of the correction factors make the resultant numerical values smaller.

2. DISCUSSION OF TRANSMISSION FORMULAS

The power of wave length in the denominator is different in the several formulas. Thus when a coil aerial is used for both transmitter and receiver the received current is inversely proportional to the cube of the wave length. Thus transmission between coils is better the shorter the wave length. This advantage of coils at short wave lengths applies only for short-distance transmission. When the distance is hundreds or thousands of kilometers, the increased absorption of the waves makes the correction factor F_1 so great that short waves are impractical, so for long distances the comparison favors the antenna rather than the coil. The coil compares most favorably with the antenna, then, for transmission over short distances with very short waves. This is subject to the proviso that current of the same order of magnitude can be gotten into a transmitting coil aerial as into an antenna, or that the resistance of a receiving coil is the same as that of a receiving antenna. Neither of the assumptions is wholly fulfilled, in practise, with the result that the difference of applicability of the two kinds of aerials at long and short wave lengths is less marked. For additional comparisons of antennas and coils and further discussion, see Sec. IV above.

Limitations of Formulas. The formulas can not be expected to give results of great accuracy, certainly not better than a few per cent, because of the ideal conditions assumed in their derivation. Thus it is assumed that no image of the aerial exists in the ground beneath it, that is, the ground is not perfect as a conductor. As a matter of fact, the ground varies greatly in conductivity; and while in most cases the currents induced in the ground below a transmitting or receiving aerial probably have very little effect, these currents may be appreciable in some cases. This is discussed further below under "Height of Aerial." On account of the uncertainty introduced by the ground, the formulas may apply better to airplane aerials than to those on ships or on land.

There are other sources of uncertainty in the application of these formulas. An antenna does not form a flat-plate condenser with the ground of such form that the curving of the field at the edges can be neglected. The simple method of calculating the radiated field is thus in doubt. Similarly, in the case of a radiating coil, the field from the top and bottom of the coil may have some effect at a distance, which has not here been taken into account. It is not certain with how great propriety the earth's surface can be taken to be equivalent to the equatorial plane of the radiating aerial. Frequently radio waves have a wave front that is tilted and not perpendicular to the earth's surface as assumed in the calculation of received current. Furthermore, the formulas assumed uniform current throughout the aerial, which sometimes does not hold because the antenna may have a vertical portion of appreciable capacity or the coil may have rather large distributed capacity. Calculations involving coil aerials are subject to the additional uncertainty arising from the capacity of the coil to ground or the surroundings so that it acts like an antenna as well as a coil. This is discussed under "Antenna Effect" in Sec. VI 3. Another difficulty discussed in the same Sec. is the effects of surrounding objects.

With these departures in the action of the aerials and the behavior of the waves from the conditions assumed, it is impossible to calculate received currents with great accuracy. It is almost surprising that the experimental results check the formulas as closely as shown in Sec. VI 2 below.

Height of Aerial. The value used for h is the length of the vertical side of a coil aerial, the distance from the surface of the ground to the flat top of an antenna, or the vertical distance between the two flat plates of a condenser aerial. In previous discussions it has been assumed that the ground beneath an antenna was a perfect conductor and thus the height of the radiator was twice the value of the h defined here. Experiment however corroborates the view here taken, which assumed that the radiating structure is independent of the earth, the waves becoming attached to the earth soon after leaving the antenna. In the present state of our knowledge the most satisfactory conception is that the radiating structure is the actual structure above the ground level. (Questions of the conductivity of the ground, presence of earth currents, etc., near the radiating aerial, are expressly not considered).

Austin's empirical formula[1] for antenna-to-antenna transmission is equation (**40**) with a constant twice as great, and quantities h_1 and h_2 used instead of h_s and h_r. These quantities h_1 and h_2 are the "height to the center of capacity" of the transmitting and receiving antenna, respectively. This height is not defined, but its value for any particular antenna is the value that is required to make experimental results fit the formula. Now, as has been stated, such experiments as have been performed agree in general with formula (**40**). For instance, see the first two examples in Sec. VI 2 below. It must follow since the constant in Austin's formula is twice as great as the constant in (**40**) that

$$h_1 h_2 = 1/2\, h_s h_r$$

This may be satisfied by various values of h_1 and h_2. One set of values would be

$$h_1 = 0.5\, h_s$$
$$h_2 = 1.0\, h_r$$

Another would be

$$h_1 = 0.707\, h_s$$
$$h_2 = 0.707\, h_r$$

Austin's values for the height of various antennas thus deduced in such a way as to make them fit the experimental values observed, do in fact vary from half to full value of the actual antenna heights, and average around 0.7 the actual heights. It is much simpler and more direct to use the formula and the interpretation presented in this paper, bearing in mind that it is subject to the uncertainties introduced by the varying character of the ground.

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[1] Scientific Paper of the Bureau of Standards No. 226, Equation 5.

The idea that the ground is not a good enough conductor to form an image of a transmitting aerial, and that the waves become attached to the ground after leaving the aerial, is in harmony with the ideas of Lodge and Muirhead, already referred to. They found that they got better transmission by using what amounted to a condenser aerial, elevated from ground, with no ground connection. This conception conflicts with the commonly accepted view that Marconi's achievement was the connection of a radiating system to the ground. What then was Marconi's achievement? The best answer to this may be one stated to the author by Prof. A. E. Kennelly, *viz.*, the use of a large radiating system, arranged vertically.

VI. EXPERIMENTAL VERIFICATION OF FORMULAS

1. PRINCIPLES OF MEASUREMENT OF RECEIVED CURRENT AND VOLTAGE

The formulas presented in this paper not only make it possible to calculate approximately the field intensity produced or current received with given aerials, but also give the basis for determining what constants to select for the circuit of a particular aerial to secure the maximum effect. In other words, these formulas furnish the principles of design of aerial circuits. There are a great many points not obvious from mere inspection of the formulas, which are of importance equally in design and in the measurement of received signals. These will now be considered. While this discussion is limited to what takes place in receiving aerials, the same principles and treatment can readily be applied to transmitting aerials.

The received current or voltage can be measured in a number of different ways. It is important to know just what quantity is being considered or measured. Suppose an indicating instrument *G*, which may be a galvanometer or a telephone receiver, is connected to a rectifying device *D* in parallel with the condenser of the receiving circuit, as in Fig. 7, where either *L* is a coil aerial or else *C* is an antenna or condenser aerial. Does the indication of the instrument measure directly (a) the e.m.f. which the wave causes to act on the circuit $C\,L$, (b) the current in the circuit, or (c) the voltage across the condenser? The answer is, of course, none of these things. The system can, however, conveniently be calibrated in terms of the voltage across the condenser. This voltage V is related to the received current I_r by the relation

$$V = \frac{I_r}{\omega\,C} \tag{45}$$

and since I_r is related to the e. m. f. acting by

$$I_r = E/R, \tag{46}$$

the relation of V to E is

$$V = \frac{E}{R\,\omega\,C} \tag{47}$$

When a detecting apparatus like that of Fig. 7 is used, in which the deflections or signals depend directly on the voltage across the condenser, the results obtained with various receiving circuits will be entirely different from those obtained when the current in the circuit is directly measured, as in Fig. 8. Equations (**46**) and (**47**) show at once that the effects of varying the constants of the receiving circuit will be different, depending on whether it is E, I_r, or V that is being measured. These three quantities for a receiving antenna are, from equations (**17**), (**46**), and (**47**), for unit magnetic field intensity,

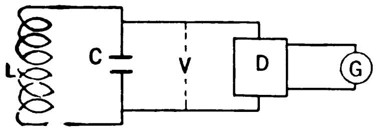

Fig. 7—Aerial Circuit with Detecting Apparatus Across the Condenser

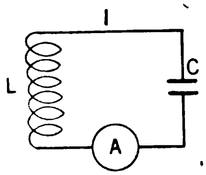

Fig. 8—Aerial Circuit with Current Measuring Instrument in Circuit

$$E_a = 300\ .\,h_r \tag{48}$$

$$I_a = 300\ .\,h_r/R \tag{49}$$

$$V_a = 300\ .\,\frac{h_r}{R\,\omega\,C} \tag{50}$$

The quantity h_r may be called the "e. m. f. reception factor" for an antenna, the e. m. f. in the receiving circuit is proportional to it. Similarly h_r/R may be called the "current reception factor" since it determines the received current. And $\frac{h_r}{R\,\omega\,C}$ or the equivalent $\frac{h_r\,L}{R\,\lambda}$ may be called the "voltage reception factor" of an antenna since it determines the voltage across the antenna.

The most favorable or optimum value of any of the variables that determine the antenna e. m. f., current, or voltage, can be determined either by direct experimental measurement of their values when actually receiving or by calculation from the reception factors. It is desired to learn simply what will produce the maximum E_a, I_a, or V_a. For example, it is obvious that E_a increases indefinitely as h_r increases, but more careful consideration is required to determine what will be the effect on the received current of increasing h_r. The reception factors furnish an alternative to direct reception measurements, requiring instead measurements upon the constants of the aerial circuit.

Coil Aerial Reception Factors. The e. m. f. applied by the passing wave to a coil aerial, the current in the circuit, and the voltage across the condenser are, from equations (**26**), (**46**), and (**47**), for unit magnetic field intensity,

$$E = 600\ .\ \pi\,\frac{a^2\,N}{\lambda} = \frac{1}{10^8}\,\frac{a^2\,N}{\sqrt{C\,L}} \tag{51}$$

$$I = 600\ .\ \pi\,\frac{a^2\,N}{R\,\lambda} = \frac{1}{10^8}\,\frac{a^2\,N}{R\,\sqrt{C\,L}} \tag{52}$$

$$V = 36\ .\ \pi^2\,10^{12}\,\frac{a^2\,N\,L}{R\,\lambda^2} = \frac{1}{10^8}\,\frac{a^2\,N}{R\,C} \tag{53}$$

These equations assume the coil to be square having both height and length $= a$. For a coil that is not square, the formulas apply, replacing a by $\sqrt{h_r\,l_r}$. Two values are given for each reception factor; the first of the two is the more useful, since it is more common to consider the dependence of the reception on λ than on C.

$$\text{E. m. f. reception factor} = \frac{a^2\,N}{\lambda} \tag{51}$$

$$\text{Current reception factor} = \frac{a^2\,N}{R\,\lambda} \tag{52}$$

$$\text{Voltage reception factor} = \frac{a^2 N L}{R \lambda^2} \tag{53}$$

Design of Receiving Coil Aerials. The response produced in a coil aerial circuit may be measured in a great variety of ways. In the first place, it may be considered either from the viewpoint of the e. m. f. acting, the current, or the voltage across the condenser. The first of these, the e. m. f., E, may be determined for any particular case from the e. m. f. reception factor in (**51**). The current I or voltage V may each be determined in four different ways: (a) by direct measurement with a suitable instrument, (b) by measurement of the quantities which make up the appropriate reception factor, (c) by measurement of signal strength in some such device as sketched in Fig. 7, which has been calibrated in I or V, (d) from a "signal intensity reception factor," which can be calculated for any signal measuring device when the law connecting the signal intensity with either I or V is known.

The design of a receiving coil requires knowledge of the dependence of the current or voltage upon the dimensions, etc., of the coil. Measurements made in all of the ways just enumerated give results in agreement with one another, provided due care is given to the avoidance of errors. The sources of error are numerous, as discussed in Sec. 3 below.

While direct measurement of the received current or voltage can be replaced by calculation from the reception factors, the fact remains that the design of an aerial requires experiments. This is because the quantity R in the reception factors cannot be obtained by calculation. It must be obtained by measurement for the particular coil and mode of connections employed.

Measurements upon receiving aerials to determine their constants and the best design for given conditions constitute a most interesting study. In later publications, the results of experiments will be published giving such data for typical coil aerials.

The capacity C in the formulas is the total capacity of the circuit, including the capacity of the coil, L is the pure inductance of the coil, and R is the actual resistance of the circuit. R includes the resistance of the conductors, effective resistance of the condenser and of the coil capacity, effective resistance of the detecting apparatus, and radiation resistance. All of these vary with frequency, and thus measurement of R at the frequency concerned is necessary. On account of the complexity of the quantities entering into the total R, its measurement is no easy matter. The capacity of the coil and other stray capacities may easily vitiate the measurement of R, C, or L. The effect of the detecting apparatus always requires most careful consideration. Even if D in Fig. 7 is an electron tube, it is necessary to consider the resistance which it introduces into the aerial circuit.

Dependence of Received Current and Voltage on Dimensions of Coil and Wave Length. Let R_c = resistance of coil and R_x = resistance external to coil;

$$R = R_x + R_c$$

$$\text{Current reception factor} = \frac{a^2 N}{(R_x + R_c)\lambda} \tag{54}$$

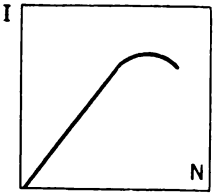

Fig. 9—Dependence of Received Current on Number of Turns

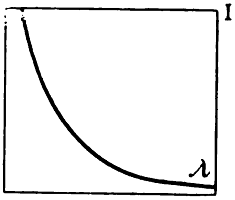

Fig. 10—Dependence of Received Current on Wave Length when External Resistance is Large

The variation of received current with number of turns, wave length, and size of coil is readily found by considering the the variation of the quantities in (**54**). In the following discussions the spacing between turns of wire, which affects resistance and inductance, is assumed constant.

a. Varying N, with λ and a constant. When R_x is large compared to R_c, we see from (**54**)

$$I \propto N$$

When R_c is large compared to R_x, since $R_c \propto N$, roughly,

$$I \propto \text{constant}$$

However, R_c increases somewhat faster than proportional to N as N is increased, because of the proximity of the added turns, and hence I decreases somewhat as N increases instead of being strictly constant.

R_x is likely to be large compared with R_c when N is very small, and hence for small N, the variation of I with N will be a straight line, as shown in Fig. 9. As N increases, R_c becomes large compared to R_x and the tendency of I to increase with N is reversed. As a result the curve of I has a maximum. The value of N at this point may be called the "optimum number of turns." Its value will be greater the greater the external resistance.

b. Varying λ with N and a constant. When R_x is large compared to R_c and does not vary appreciably with wave length,

$$I \alpha 1/\lambda$$

This variation is shown in Fig. 10. When R_c is large compared to R_x, however, since $R_c \alpha \frac{1}{\sqrt{\lambda}}$, roughly,

$$I \alpha \frac{1}{\sqrt{\lambda}}$$

However, the effect of the adjacent turns increases R_c faster than stated as λ is diminished and hence I tends to approach a constant value for short wave lengths, as shown in Fig. 11. These conclusions may, however, be vitiated by the variation of R_x with λ.

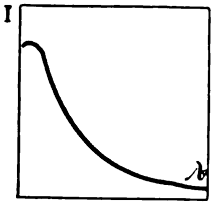

FIG. 11—DEPENDENCE OF RECEIVED CURRENT ON WAVE LENGTH WHEN COIL RESISTANCE IS LARGE

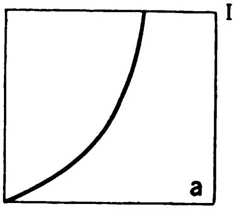

FIG. 12—DEPENDENCE OF RECEIVED CURRENT ON SIZE OF COIL WHEN EXTERNAL RESISTANCE IS LARGE

c. Varying a, with N and λ constant. When R_x is large compared to R_c,

$$I \alpha a^2$$

This is shown in Fig. 12. When R_c is large compared to R_x, since $R_c \alpha a$,

$$I \alpha a,$$

giving the straight line in Fig. 13. From these two extreme cases it follows that an actual curve is likely to have a form that is a combination of these two, as shown in Fig. 14.

d. Varying a, with λ constant, allowing N to vary in such a way that length of wire is constant. The condition is that
$N \alpha 1/a$,
When R_x is large compared to R_c,

$$I \alpha a$$

The curve of I is thus a straight line. When R_c is large compared to R_x, the same conclusion holds but only roughly. R_c increases slightly as a is decreased because of the proximity of the added turns, hence I increases a little faster than proportional to a. This is shown in Fig. 15.

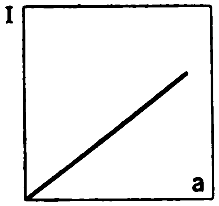

FIG. 13—DEPENDENCE OF RECEIVED CURRENT ON SIZE OF COIL WHEN COIL RESISTANCE IS LARGE

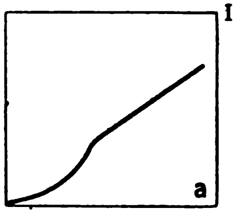

FIG. 14—DEPENDENCE OF RECEIVED CURRENT ON SIZE OF COIL IN TYPICAL CASE

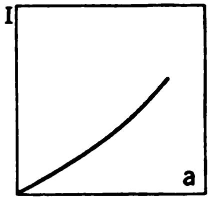

FIG. 15—DEPENDENCE OF RECEIVED CURRENT ON SIZE OF COIL WHEN LENGTH OF WIRE IS KEPT CONSTANT

The voltage reception factor differs from the current reception factor by L/λ.
Thus,

$$V \alpha \text{ Voltage reception factor } = \frac{a^2 N L}{(R_x + R_c)\,\lambda^2} \qquad (55)$$

It is thus a more complex problem to determine the variation of voltage with N, λ, and a, because the variation of L must be considered in addition. This may be done in each case, just as was done above for current, taking into account the relations:

$$L \alpha N^{2-} \qquad\qquad R_c \alpha N^{1+}$$

$$L \alpha \lambda^{0-} \qquad\qquad R_c \alpha \frac{1}{\lambda^{\frac{1}{2}+}}$$

$$L \alpha a^{1+} \qquad\qquad R_c \alpha a^{1}$$

where the + or − sign after the exponent indicates that the actual power is slightly greater or less than that given.

The relations obtained for voltage are similar to those obtained for current. There are some characteristic differences as, *e. g.*, with varying N the optimum number of turns comes out greater than for received current. Thus when the detecting apparatus depends essentially on the current the size of the coil should be as large as possible, whereas when it depends essentially on the voltage across the condenser the number of turns should be as large as possible.

On the whole, the received current or voltage or signal intensity is increased by increasing the dimensions (N and a), and by decreasing the wave length. These conclusions are subject to the limitation, discovered by French experimenters, and qualitatively obvious from the known increase of R near the natural wave length λ_0 of a circuit, that poor results are obtained if $\lambda_0 > 1/3\ \lambda$. Thus the dimensions of the coil can not be increased, or the wave length decreased, indefinitely. Beyond the limit mentioned, in fact, better results are obtained by decreasing the dimensions of the coil.

It is an interesting fact that these discussions apply not only to the design of a coil aerial for receiving signals but that they also solve the problem of design of wavemeters. The choice of constants of a wave meter coil for any particular case is settled by the formulas and ideas here presented. The considerations given for received current and voltage apply respectively to the design of wavemeters for measurements upon undamped or damped waves, *i. e.*, to the securing of minimum resistance and minimum decrement respectively.

2. EXAMPLES OF MEASUREMENTS

Measurements having as their object the verification of the transmission formulas were discussed in the preceding section. Any experiments which verify the transmission formulas may also be considered as checking the "theoretical formulas" and "comparison formulas". In fact experimental tests of the transmission formulas are the most rigorous test of the theory presented in this paper. All of the limitations and errors discussed in Sec. V 2 affect the transmission formulas while only a portion of them affect the theoretical and comparison formulas.

The complicated practical conditions of any experiment, the tilting of the wave front, the combination of antenna and coil effects discussed in the next section below, and other uncertainties make close agreement between theory and experiment unlikely. Agreement to 30 per cent should be considered as highly satisfactory verification of the essential correctness of the theory. On account of its field being more definitely localized, experiments with a coil aerial may be expected to yield greater accuracy than experiments with an antenna. The same advantage appertains to a condenser aerial. No quantitative data have been obtained with condenser aerials, to the author's knowledge; such experiments would be very desirable.

Experimental data obtained at the Bureau of Standards on radio transmission and reception are presented below. The agreement between the received current observed and the values calculated from the transmission formulas can be considered as very satisfactory. The author is informed that experiments made by the Signal Corps have led to a similar verification. In some of the Signal Corps experiments it was thought at one time that wide departures from the transmission formulas for coil aerials were observed, the received current for very short waves being much less than the transmission formulas indicated. When, however, the actual values of the resistance at wave lengths used were determined, the agreement was very good. Particular care must be given to proper measurement of the resistance of the receiving aerial circuit.

Antenna to Antenna. Experiments which supply a check on formula (**40**) have been published by Dr. Austin, chief of the Naval Radiotelegraphic Laboratory located at the Bureau of Standards.

For transmission between two antennas located on ships (*Jour. Wash. Acad. Sciences,* 1, p. 275; 1911), $h_s = 29.2$, $h_r = 29.2$, $I_s = 30.$, $R = 25.$, $\lambda = 1000.$, $d = 1000$. The lengths given in all these examples are in meters. Calculating from (**40**),

$$I_r \text{ calculated} = 0.19$$
$$I_r \text{ observed} = 0.21$$

For the Washington Navy Yard antenna transmitting to an antenna at the Bureau of Standards (*Bull. Bureau of Standards,* 11, p. 74; 1914), $h_s = 36.$, $h_r = 30.$, $I_s = 7.0$, $R = 70.$, $\lambda = 2800.$, $d = 10{,}000$. Calculating from (**40**) and (**20**)

I_r calculated $= 0.53$
I_r observed $= 0.55$

As already pointed out, the agreement of observed values with the transmission formulas indicates that it is proper to take as the antenna height the actual height from the ground to the flat top.

Antenna to Coil. A number of experiments to check the antenna-to-coil transmission formulas have been made at the Bureau of Standards radio laboratory since early in 1917. The first ones did not involve quantitative measurements but served to give a rough check on the formulas. The calculated value of current was compared with the current as estimated from the loudness of signal in a telephone receiver connected to various types of detecting devices. These signals were interpreted on the assumption that a fairly audible response is given by the currents indicated with the several types of detector.

10^{-2} ampere, thermoelement.
10^{-4} ampere, crystal detector.
10^{-6} ampere, simple audion.
10^{-8} ampere, oscillating audion.

For the Arlington antenna received on a coil aerial at the Bureau of Standards, $h_s = 122.$, $h_r = 4.$, $l_r = 4.$, $N_r = 22.$, $I_s = 102.$, $R = 25.$, $\lambda = 3800.$, $d = 7800.$ The received current calculated from (**41**) is 0.0018 ampere. The observed signal using crystal detector and telephone, was very loud, thus checking in a qualitative way the result calculated value.

Two similar qualitative experiments were made, transmitting from an antenna at the Bureau of Standards and receiving on a portable coil aerial. In one experiment, $h_s = 36.$, $h_r = l_r = 1.07$, $N_r = 11.$, $I_s = 0.5$, $R = 2.$, $\lambda = 850.$, $d = 16{,}000.$, whence calculated $I_r = 11. \times 10^{-6}$. In the other, $h_s = 12.$, $h_r = l_r = 1.07$, $N_r = 11.$, $I_s = 0.25$, $R = 2$, $\lambda = 600.$, $d = 11{,}000.$, whence calculated $I_r = 5.7 \times 10^{-6}$. In both cases the observed signal was loud with a simple audion, again giving a qualitative check on the formula.

A number of experiments have been made by Dr. Austin during 1918 and 1919, who has kindly placed the results at my disposal. A couple of typical ones will be given. For the Arlington antenna transmitting to a coil aerial at the Bureau of Standards, $h_s = 122.$, $h_r = 1.82$, $l_r = 1.29$, $N_r = 56.$, $I_s = 100.$, $R = 50.$, $\lambda = 6000.$, $d = 7800$.

I_r calculated $= 1.4 \times 10^{-4}$
I_r observed $= 2.1 \times 10^{-4}$

For the same antenna transmitting to a large coil suspended from masts outdoors, $h_s = 122.$, $h_r = 21.6$, $l_r = 24.4$, $N_r = 7.$ $I_s = 100.$, $R = 50.$, $\lambda = 10{,}000.$, $d = 7800.$, $\alpha = 42$ deg. From (**41**) and (**24**),

I_r calculated $= 1.0 \times 10^{-3}$
I_r observed $= 1.2 \times 10^{-3}$

A large number of transmission experiments from antenna to coils have been made by the radio laboratory of this Bureau in the early part of 1919. In a typical case, where $h_s = 21.$, $h_r = l_r = 1.44$, $N_r = 8.$, $I_s = 3.$, $R = 7.7$, $\lambda = 700.$, $d = 4800.$, $\delta' = 0.1$, $L = 541.$ microhenries. From (**41**) and (**20**),

I_r calculated $= 24. \times 10^{-6}$
I_r observed $= 28. \times 10^{-6}$

The fact that the observed current is larger than the calculated, in these and other cases, is probably due to the antenna effect, discussed in the next section. The coil structure has capacity, which makes it receive the wave by antenna action in addition to the coil action, thus increasing the current actually received.

Coil to Antenna. In an experiment made by Dr. Austin, with a large coil at the Bureau of Standards transmitting to the Arlington antenna, $h_s = 21.6$, $l_s = 24.4$, $h_r = 122.$, $N_s = 4.$,
$N_s = 7.$, $I_s = 1$, $R = 50.$, $\lambda = 2800.$, $d = 7800$, $\alpha = 42$ deg. From formula (**42**),

I_r calculated $= 1.3 \times 10^{-4}$
I_r observed $= 1.5 \times 10^{-4}$

Coil to Coil. The only data available to the author on the use of the coil aerial for both transmitting and receiving are from experiments made in 1917 by Messrs. Kolster, Willoughby, and Lowell, and these are only qualitative. For transmission from a coil at the Bureau of Standards to a portable coil 40. kilometers away, $h_s = l_s = 3.$, $h_r = l_r = 1.$,

$N_s = 4.$, $N_r = 15.$, $I_s = 10.$, $R = 1.$, $\lambda = 600.$, $d = 40{,}000$. The received current calculated from formula (**43**) is 4.6×10^{-6}. The observed signal was loud with a simple audion.

For transmission from a coil located at a lighthouse to a coil on a ship 48 kilometers away, $h_s = l_s = 3.05$, $h_r = l_r = 1.22$, $N_s = 3.$, $N_r = 10.$, $I_s = 10.$, $R = 2.$, $\lambda = 550.$, $d = 48{,}000$. The calculated I_r is 1.6×10^{-6}. The observed signal was audible on a simple audion. Comparing with the current sensibility of an audion stated above, it is seen that both of these results furnish a rough check on the formula.

3. DISCUSSION OF EXPERIMENTS

The agreement of the experiments with the theory is highly satisfactory in view of the simple conditions assumed in the theory. The complex practical conditions preclude the likelihood of agreement within a few per cent. The various limitations of the formulas arising from actual experimental conditions are discussed above in Sec. V 2.

One characteristic of the experiments with coil aerials is that the observed value of received current is in every case greater than the calculated value. This strongly suggests that the action of the coil structure involves something additional to the pure action as a coil. This would be expected also from theoretical considerations. The inevitable capacities between parts of the aerial circuit must introduce an action analogous to that of an antenna. When it is borne in mind that the coil action is really a second-order effect in comparison with the action of a system of antenna nature, it appears extremely likely that the stray capacities of any coil aerial circuit would introduce an antenna effect which would have to be considered in addition to the pure coil effect. Besides the reasons thus given by theory and by the excessive values of current observed in experiments with coil aerials, there are two other lines of evidence that the antenna effect is not negligible in coil aerials.

One of these additional lines of evidence is furnished by measurements of current in different parts of a coil aerial or the circuit thereof. If the capacities between parts are appreciable some of the current must leave the conductors and flow off into the dielectric; the current observed with an ammeter must therefore be different in different parts of the circuit. These differences are actually found. The fourth kind of evidence that the antenna effect is appreciable in coil aerials is furnished by considerations of radiation resistance, which will now be discussed. Following that, the antenna effect will be considered in more detail.

Radiation Resistance. It is possible to determine whether in a given system the antenna effect or coil effect predominates by measurements of radiation resistance. The radiation resistance has different values and follows different laws for antenna and coil.

Radiation resistance in general is defined by

$$P = R\,I^2 \tag{56}$$

in which I is the current in the aerial used as a transmitting device, P is the power radiated, and R the radiation resistance. The study of radiation resistance is an important means of facilitating work on aerials. This may be seen from the simple fact that the magnitude of the radiation resistance gives at once the power radiated, and hence the effectiveness of a transmitting aerial or the range of communication can be judged without making transmission experiments. Field tests are thus in large part replaced by laboratory measurements. In addition to this, it is possible to discriminate between the antenna and coil effects.

The magnitude of the radiation resistance of a flat-top antenna, at wave lengths considerably greater than the fundamental, is given by the well-known expression

$$R_a = (39.7\,h/\lambda)^2 \tag{57}$$

An approximate expression for the radiation resistance of a coil can be derived very simply, as follows. When a radiated field exists in any part of space, the relation of the power radiated through that portion of space to the magnetic field intensity there existing is

$$P' \alpha H^2 \tag{58}$$

for any given distance from the source, whatever the source may be. The total power radiated is proportional to the integral of P over any surface entirely surrounding the source. This integral will be of the same form for H_c, the field due to a coil, as for H_a, the field to an antenna, except for the effect of the variation of H_c in a plane around the radiating coil, which varies from zero to the value given in (**10**) for any given distance from the source. As a first approximation, this variation may be considered to make the integrated value of H_c one-half as great as it would be if H_c had the value given in (**10**) in all directions around the radiating coil.

$$\therefore \frac{P_c}{P_a} = \frac{1}{2} \frac{H_c^2}{H_a^2} \tag{59}$$

From (**8**) and (**10**), for a given distance from the source and a coil and antenna of same height with same current,

$$\frac{H_c}{H_a} = 2\,\pi\,\frac{l\,N}{\lambda} \tag{60}$$

From (**56**),

$$\frac{R_c}{R_a} = \frac{P_c}{P_a}$$

Hence from (**59**) and (**60**)

$$\frac{R_c}{R_a} = 2\,\pi^2\,\frac{l^2\,N^2}{\lambda^2}$$

Inserting the value of R_a from (**57**)

$$R_c = 31{,}100.\,\frac{h^2\,l^2\,N^2}{\lambda^4}$$

If the coil is a square one with $h = l = a$,

$$R_c = (13.3\,a/\lambda)^4\,N^2 \tag{61}$$

This approximate expression for radiation resistance of a coil gives at once the variation with size, number of turns, and wave length. *E. g.*, for a set of coils of varying size, in which the length of wire is kept constant, $R_c \propto 1/N^2$. It shows that for a given ratio of size to wave length, $R_c \propto N^2$. The principal point of interest is that R_c is inversely proportional to the fourth power of wave length.

Since the radiation resistance of an antenna is inversely proportional to the second power of wave length, and that of a coil inversely proportional to the fourth power, the radiation resistance furnishes a means of determining whether a given structure functions as a coil or as an antenna. Rough determinations of radiation resistance which were made upon a particular coil aerial showed a variation of observed radiation resistance inversely as the third power of the wave length, thus verifying the idea that the action is a combination of coil and antenna effect. The observed values however were all higher than the sum of the theoretical R_a and R_c. The measurement of radiation resistance is an extremely difficult operation, and satisfactory methods can not be said to have been developed as yet.

Antenna Effect. Since there are differences of potential between various parts of a coil, acting either as a transmitting or receiving aerial, there must be some dielectric current through the space around the coil and between the coil and ground. It follows that there must be some antenna action, proportional to the amount of this dielectric current and the length of path over which it flows, and this will produce a current additional to that produced by the coil action unless the coil structure happens to have an exact symmetry which causes the antenna effect in each part of the coil to be balanced by an antenna effect in some other part.

Fig. 16 shows the origin of the antenna effect. As in ordinary practice, the leads cause some part of the apparatus to be practically at ground potential, the shield of the condenser is shown connected to ground. An appreciable dielectric current flows from various parts of the conducting circuit to other parts and to ground. Typical paths of this dielectric current are shown by the dotted lines. The line *a b* suggests the dielectric current from the coil structure to ground, the lines *c d* and *e f* the dielectric current between turns of the coil, and the line *g h* the dielectric current between coil and leads. The flow of dielectric current between turns of the coil is in a horizontal direction when the coil is of prismatic form with the turns separated and all of the same area. This part of the antenna effect arises in a receiving coil of this form only when the wave front is more or less tilted from the vertical.

On account of the flow of current off through the dielectric from various parts of the circuit, ammeters placed at different places in the circuit would show different values of current to be flowing. In radio circuits it can not be assumed that the current is the same at all points around the conducting circuit, as was shown by the author in his investigation of high-frequency current measurement described in *Bureau of Standards* S. 206; 1913.

To the extent that these dielectric currents flow, the conductors of the circuit may be considered as an antenna system. Perhaps only the current typified by the line *a b* might be thought of as giving rise to an "antenna" effect, since the others do not flow to ground; still this part of the dielectric current does not differ from the others in nature or effect, and it seems hence advisable to use the suggestive term "antenna effect" to indicate all of the effects arising from the presence of currents in the dielectric.

It might be supposed that the same sort of an effect would be caused by the flow of dielectric current in the condenser of the coil aerial circuit. This is not true ordinarily because a condenser of the laboratory type is used, in which the condenser plates are interleaved. As shown in Fig. 17, the current in one direction in the dielectric is balanced by a current in the opposite direction in the neighboring part of the condenser. This is a non-radiating condenser; and is the analog of a non-inductive coil, which is also non-radiating. A condenser consisting of a single pair of plates would radiate, but is not ordinarily used because it would be much bulkier than the laboratory type of condenser. The condenser consisting of a single pair of plates would be in fact the "condenser aerial," which has been recommended by the author in Sec. IV 3 as worthy of serious consideration in radio practise.

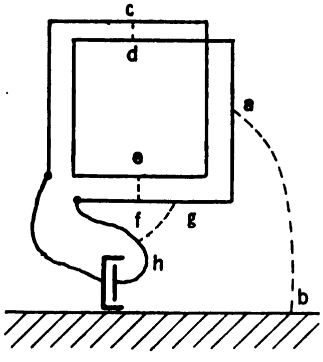

FIG. 16—PATHS OF DIELECTRIC CURRENTS WHICH CAUSE ANTENNA EFFECT IN COIL AERIAL

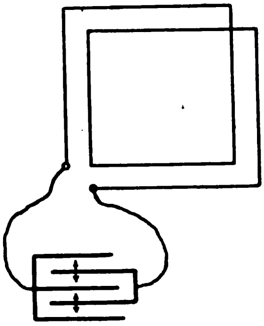

FIG. 17—DIRECTIONS OF FLOW OF DIELECTRIC CURRENTS IN LABORATORY TYPE OF CONDENSER

The effect of the distributed capacities of the aerial circuit must not be confused in any way with the phase angle between the fields existing at the two vertical sides of the coil aerial. The phase angle referred to is the seat of the action of the coil aerial as such. The dielectric currents flowing in the distributed or stray capacities of the circuit, however, give rise to the direct action as an antenna, not depending in any way on the separation between the two vertical sides of the coil. All of these remarks apply both to transmission and reception.

It is rather difficult to determine what fraction of the effect of a coil aerial is due to antenna action and what part to coil action. In many cases, doubtless, the antenna action predominates. It is possible, however, to separate the effects in any particular case by the several different methods. The antenna effect may be calculated, at least for parts of the circuit, by the aid of careful ammeter readings which show what amount of the current has flowed off into the dielectric. The antenna effect may be eliminated, thus leaving only the coil effect, by a carefully arranged system of shields and grounds; or, by a symmetrical arrangement of the coil structure which causes the antenna effect in each part to be balanced by the antenna effect in some other part. The coil effect may be eliminated, on the other hand, in the case of a receiving coil, by taking advantage of the fact that the coil effect depends on the direction of orientation while the antenna effect (at least the major part of it) does not; *i. e.*, by turning the coil so its plane is parallel to the wave front. A method which eliminates the coil effect and retains a part of the antenna effect is to open one of the coil leads, thus leaving the coil aerial connected to the circuit at one point, placing in series with it an inductance coil of very small dimensions but of the same inductance, the circuit being completed by the capacity of the coil aerial to ground.

Effects of Surroundings. Currents are induced in metal and other objects near a transmitting aerial, and sometimes are powerful enough to affect the radiation appreciably. The objects near a receiving aerial have currents produced in them by the passing wave. These currents in nearby objects, which may include the ground, induce e. m. f's. in the receiving aerial. It is to be noted that this effect of neighboring objects is caused by induction, and not radiation from them, which would be comparatively feeble.

The e. m. f. thus induced in a coil aerial from the surroundings is of the same or opposite phase as that caused by the wave. It differs in this respect from the e. m. f. due to the antenna effect discussed above. The antenna effect ordinarily produces an e. m. f. which is 90 deg. out of phase with the coil effects and does not vary with the orientation of the coil. The antenna effect can thus never balance out the coil effect, and it is impossible to reduce the received current to zero no matter how the coil is turned. The e. m. f. induced by the surroundings, however, depends upon the orientation of the coil. This e. m. f. will be reduced to zero by turning the coil at a different orientation from that at which the e. m. f. due to the wave is zero, unless the line between distorting object and the coil aerial is the direction of propagation of the wave. The result of this is that the total e. m. f. is reduced to zero at some orientation other than that obtained when the wave alone acts on the coil aerial. There is thus a distortion in the apparent direction of the wave, caused by objects surrounding the coil aerial.

VII. PRACTICAL CONCLUSIONS

1. Relative Effectiveness of Antennas and Coil Aerials

a. Generally speaking, a coil aerial is as powerful a transmitting or receiving device as an antenna only when its dimensions approach those of the antenna.

b. It is easy to make the resistance of a coil aerial circuit much smaller than the resistance of the ordinary antenna circuit and thus make a small coil as effective as a large antenna. A small aerial as effective as a large antenna can however also be secured by the use of the antenna-like aerial called the condenser aerial. Heeding these principles and using amplifiers in receiving, radio aerials can in the future be much smaller than heretofore.

c. The relative effectiveness of a coil and antenna, in terms of the wave length, number of turns, etc., is given by formula (**33**) and the related formulas.

d. A coil aerial exhibits antenna action as well as coil action, because of capacities between its parts and surroundings. The antenna action sometimes overbalances the coil action.

e. The advantage of the coil aerial is greatest for short wave lengths. It is consequently likely to be well suited to airplane communication. The increasing advantage of the coil as a transmitting aerial, as the wave length is decreased, is subject to the proviso that the same current can be gotten into a coil as into an antenna. In fact, the whole practical problem is to get as much current as possible into the aerial.

f. The use of coil aerials at both receiving and transmitting ends of the communication is particularly suitable for short waves, since the received current in such a system is inversely proportional to the cube of the wave length.

2. PRINCIPAL FORMULAS

The units used are international electric units, the ordinary electric units based on the ohm, ampere, centimeter, and second; except where otherwise stated. The principal symbols are the following.

SYMBOLS

i = instantaneous current.
I_0 = maximum value of current.
I = effective value of current.
H_t = instantaneous value of magnetic field intensity.
H_0 = maximum value of magnetic field intensity.
H = effective value of magnetic field intensity.
h = height of aerial.
d = distance along earth's surface from sending aerial.
ω = 2π times frequency of the current.
t = time.
λ = wave length.
c = velocity of electric waves = 3×10^{10} cm. per second.
l = horizontal length of coil aerial.
N = number of turns of wire of coil aerial.
a = length of side of square coil.
θ = phase angle between values of field intensity a distance l apart in the wave.
$\mathcal{E}$ = electric field intensity.
E = electromotive force in receiving aerial.
δ' = logarithmic decrement of H or E.
ϕ = magnetic flux.
R = resistance of receiving aerial circuit.
C = capacity of receiving aerial circuit.
L = inductance of receiving aerial circuit.
α = angle between direction of propagation of wave and plane of coil.

Subscripts: s = sending, r = receiving, a = antenna, c = coil.

The following are the principal formulas presented in this paper:

Radiated Magnetic Field Intensity from an Antenna or Condenser Aerial.

$$H = \frac{2\,\pi}{10}\,\frac{h_s\,I_s}{\lambda\,d} \tag{8}$$

Radiated Magnetic Field Intensity from a Coil.

$$H = \frac{4\,\pi^2}{10}\,\frac{h_s\,l_s\,N_s\,I_s}{\lambda^2\,d} \tag{10}$$

Received Current in an Antenna or Condenser Aerial.

$$I_r = 300\,.\,\frac{h_r\,H}{R} \tag{19}$$

Received Current in a Coil.

$$I_r = 600\,.\,\pi\,\frac{h_r\,l_r\,N_r\,H}{R\,\lambda} \tag{23}$$

Distance Correction Factor.

$$F_1 = \epsilon^{-0\cdot000047\,d\,/\sqrt{\lambda}} \tag{9}$$

Decrement Correction Factor.

$$F_2 = \sqrt{\frac{1}{1 + \dfrac{600\,.\,L\,\delta'}{R\,\lambda}}} \tag{20}$$

Direction Correction Factor.

$$F_3 = \cos\alpha \tag{24}$$

Antenna-to-Antenna Transmission.

$$I_r = \frac{188\,.\,h_s\,h_r\,I_s}{R\,\lambda\,d} \tag{40}$$

Antenna-to-Coil Transmission.

$$I_r = \frac{1184\,.\,h_s\,h_r\,l_r\,N_r\,I_s}{R\,\lambda^2\,d} \tag{41}$$

Coil-to-Antenna Transmission.

$$I_r = \frac{1184\,.\,h_s\,l_s\,h_r\,N_s\,I_s}{R\,\lambda^2\,d} \tag{42}$$

Coil-to-Coil Transmission.

$$I_r = \frac{7450 . h_s l_s h_r l_r N_s N_r I_s}{R \lambda^3 d} \tag{43}$$

The lengths in the four preceding formulas may be in any units. Meters are commonly used. Any of these formulas may be expressed in terms of d. *E. g.,*

Distance at Which a Given Current is Received in a Coil for a Given Transmitting Current in an Antenna.

$$d = \frac{1184 . h_s h_r l_r N_r I_s}{R \lambda^2 I_r} \tag{44}$$

Total Magnetic Field from an Antenna, Including Radiation and Induction.

$$H = \frac{2 \pi}{10} \frac{h_s I_s}{\lambda d} + \frac{j}{10} \frac{h_s I_s}{d^2} \tag{31}$$

Relative Effectiveness of Coil and Antenna, for Same Height and Wave Length.

$$d_c/d_a = N \sqrt{2 (1 - \cos 2 \pi l/\lambda)} \tag{32}$$

Ditto, l small compared to λ.

$$d_c/d_a = 6.28 N l/\lambda \tag{33}$$

Length of Coil Aerial Equivalent to Antenna of the Same Height.

$$l = 0.16 \lambda/N \tag{39}$$

Current in Aerial Circuit.

$$I_r = E/R \tag{46}$$

Voltage across Condenser in Aerial Circuit.

$$V = \frac{E}{R \omega C} \tag{47}$$

Coil Aerial Reception Factors.

$$\text{E. m. f. reception factor} = \frac{a^2 N}{\lambda} \tag{51}$$

$$\text{Current reception factor} = \frac{a^2 N}{R \lambda} \tag{52}$$

$$\text{Voltage reception factor} = \frac{a^2 N L}{R \lambda^2} \tag{53}$$

Radiation Resistance.

$$R_a = (39.7\,h/\lambda)^2 \tag{57}$$

$$R_c = (13.3\,a/\lambda)^4\,N^2 \tag{61}$$

3. FUTURE RESEARCH NEEDED

The subject of research on electric waves can be considered as barely begun. The study presented in this article has revealed vast and most interesting problems awaiting solution which can be solved. The functioning of aerials, both in transmitting and receiving, can now be considered as roughly understood. Recent advances in radio measurements and technique open the way to experiments and progress which will bring about far-reaching control of electric waves. A few of the detailed problems which border on the subject matter of this paper and await solution will now be mentioned.

Theoretical Problems.

a. Develop a simple and straightforward derivation of the radiated field from a coil, without consideration of shape of the coil or dealing with the electrostatic field at all.

b. Work up an explanation of the mechanism of radiation that brings out clearly the relation of the radiation to the induction field and shows that all of the dielectric current is effective in causing radiation, which shall take the place of the usual explanation in terms of the snapping off of lines of force.

c. Determine the effects of the phase angle between different parts of the dielectric field in an antenna or condenser aerial, especially the long, low types.

d. Develop methods of measuring radiation resistance.

e. Work out laws of variation of voltage reception factor of coil aerials, and laws of variation of both current and voltage reception factors of antenna and condenser aerials. Similarly, develop accurate and useful transmission factors.

Experimental Problems.

a. Determine the relative effectiveness over a very wide range of sizes, wave lengths, etc., of the various types of aerials. Do this by: (1) direct measurements to verify transmission formulas (2) measurements of the factors that enter into the reception factors, (3) measurements of radiation resistance.

b. Make transmission experiments at very great distances over typical kinds of land, to obtain distance absorption factors.

c. Try out condenser aerials, comparing performance with transmission formulas. Build such aerials with minimum resistance. Demonstrate the non-radiating nature of the laboratory type of condenser, comparing it with condenser aerials.

d. Compare trailing wire, condenser aerial, and coil aerial, on airplane.

e. Find out how directive as transmitting devices coil and condenser aerials and "earth antennas" are; measure magnitude and direction of field at various distances from the aerial, at numerous wave lengths, etc.

f. Determine relative magnitudes of induction and radiation close to transmitting aerials. Determine also directions of fields, to secure complete knowledge of phenomena near radiating systems.

g. Measure currents in ground as well as the fields above the ground, to determine how wave attaches itself to the ground.

h. Study distributed capacities in coil aerial circuit by measuring current at different points in circuit.

i. Determine values of antenna effect, and develop means of controlling or eliminating it by shielding systems, etc.

j. Make quantitative investigation of receiving systems combining antenna and coil aerial. Measure phase of currents. Determine under what circumstances the indication of absolute direction is reversed when the tuning is slightly varied.

k. Determine effects of surrounding objects on currents in transmitting and receiving aerials. Measure magnitude and phase of currents in typical cases.

l. Develop methods of connecting generating apparatus to various types of aerials to get maximum current into the aerial, especially at short wave lengths.

VIII. SUMMARY

The advantages of the coil aerial as a direction finder, interference preventer, reducer of strays, and submarine aerial make it important to know how effective the coil aerial is, in comparison with the ordinary antenna, as a transmitting and receiving device. This article gives the answer. Simple formulas are worked out from fundamental electromagnetic theory, by which the performance of any aerial can be calculated. Experiments have verified the formulas, and show that they are a valuable aid in the choice and design of an aerial to fit any particular requirements.

The principal formulas are of three kinds: theoretical formulas, giving the magnetic field intensity at any distance from either kind of aerial and the current produced by a given field intensity in either kind of aerial; comparison formulas, giving the ratio of performance of antenna and coil aerial under various conditions; and transmission formulas, giving the current in any receiving aerial in terms of the current in the distant transmitting aerial.

The theory and nature of radiation are discussed, and applied to the elucidation of some current fallacies. There has been a vast haziness of ideas on these points. The distinction between induction fields and radiation fields is presented. It is shown that the receiving action in any kind of an aerial may be considered as arising either from the electrostatic or the magnetic field present in the wave. Such questions are discussed as the distinction between "open" and "closed" circuits. It is shown that a metallically closed circuit can radiate, and that radiation takes place at all frequencies, the amount of radiation being greater the higher the frequency.

The ratio of the range of communication obtainable with a coil aerial to that with an antenna is proportional to the number of turns and horizontal length of the coil and inversely as the wave length. The coil aerial is hence particularly suited to communication on short wave lengths. A coil aerial is quantitatively as powerful as an antenna only when its dimensions approach those of the antenna. However, it is easy to make the resistance of a coil aerial circuit much smaller than the resistance of the ordinary antenna circuit and thus make a small coil as effective as a large antenna.

A small aerial as effective as the ordinary antenna may be secured without recourse to the coil principle by using an aerial consisting of a condenser having two large parallel plates, arranged so that the dielectric of the condenser includes no ground. The circuit of such an aerial may be made to have a very low resistance. It appears likely that, with the use of either condenser or coil aerials together with sensitive amplifiers, radio aerials will in the future be much smaller than heretofore. These principles apply with particular advantage to airplane aerials.

A coil aerial usually functions by a combination of the pure coil action and antenna action. The latter arises from the stray capacities and capacities to ground which are inevitably present. The existence of these capacities may be shown by differences in ammeter readings at different points of the circuit. The antenna effect makes the actual received current in experiments with coil aerials larger than the values calculated from the transmission formulas. The observed values are also affected by currents in neighboring objects.

A formula for the radiation resistance of coil aerials is worked out. Comparison of experiment with this formula supplies additional evidence that the coil aerial operates by a combination of antenna and coil effects.

The fundamental principles of design of aerials are given. The various modes of measuring received current and voltage across the condenser are discussed. The relations of these two quantities to the electromotive force acting in the aerial must be carefully observed in calculations or design. Reception factors are derived, to which the received current or voltage are proportional. Experimental data on the functioning of aerials may be secured either from actual transmission experiments or from measurements of the quantities which enter into the reception factor.

This investigation has opened up a large and most interesting field for further research. Progress in the control and utilization of electric waves depends on the investigation of such theoretical and experimental problems as have been suggested in Sec. VII 3 herein.

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A REPORT ON ELECTROMAGNETIC INDUCTION[1]

BY S. J. BARNETT

ABSTRACT OF PAPER

This report discusses briefly the chief fundamental results obtained from the days of Faraday to the present time in studying the electromotive forces ordinarily referred to the domain of electromagnetic induction.

Self-induction is first taken up, and the phenomena of self-induction are treated as essentially identical with the phenomena of inertia in dynamics, according to the idea of Maxwell and the idea originally accepted by Faraday. The only recent fundamental progress has been in studying the inertia of free electrons and other ions, and experiments on this subject are referred to.

The motional electromotive force, developed when matter moves in a magnetic field, is next considered, and is derived from Ampère's law on the electron theory. Especial attention is devoted to the motional intensity, and the resulting electric displacement, in insulators, of which nothing has been known until recent years.

The induced electromotive force in fixed conductors and insulators arising from the motion or alteration of other systems is next considered, and is expressed both in terms of magnetic flux and in terms of the general vector potential, which refers the phenomena back to the motion of electrons without the magnetic field as intermediary. The relations between the induced and motional electromotive forces are discussed, as well as the relation of the electric displacement produced in certain cases to the hypothesis of the fixed aether.

The report closes with a treatment of unipolar induction in both so-called open and closed circuits, including brief descriptions of some of the principal experiments, a discussion of the theories involved, and their application to the unipolar generator.

1. IT is unnecessary to emphasize the great importance of this subject alike to the physicist and to the engineer. The world of the physicist is rapidly becoming fundamentally an electrical world, in which a vast part is played by electromagnetic induction; and without electromagnetic induction the world of the electrical engineer could scarcely be considered even to exist.

The general field of electromagnetic induction has become very broad, and it will be necessary to restrict this discussion to fundamental matters, and from among them to select for consideration only electromotive forces and electric displacements, and these only in stationary or quasi-stationary systems. Important related subjects such as the transfer of energy in the electromagnetic field according to Poynting and Heaviside must be excluded. Even the principle of relativity can scarcely be more than mentioned.

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[1] For references see end of paper.

To a very remarkable degree our knowledge of the fundamental facts and principles of electromagnetic induction is due to Michael Faraday. Most of the progress made by others has consisted in increasing the precision of his measurements and in developing ideas which originated in less perfect form with him.

2. The principal experiments of Faraday and his contemporaries in the field of electromagnetic induction may conveniently be grouped in four divisions, as follows:

I. Experiments in which the agent producing the magnetic field remains fixed to the earth and the conductor or insulator under examination moves. The electric intensity and electromotive force in the body due to the motion have been called the *motional* intensity and e. m. f. by Heaviside.

II. Experiments in which the body under examination remains fixed to the earth, and the agent producing the magnetic field moves or its electric current changes.[2] The electric intensity and e. m. f. produced under these circumstances will be called the *induced* intensity and e. m. f., although these terms are often applied also to the motional quantities.

According to the Einstein principle of relativity, no discrimination can be made between the motional and induced intensities, as only the relative motion of two bodies can be determined.

III. Experiments on unipolar induction, strictly belonging to groups I and II, but to be considered separately for convenience.[3]

IV. Experiments on self-induction.

3. The last group, on self-induction, will be considered first. When a steady electromotive force is applied to a circuit the current increases from zero until a steady value is reached when the counter e. m. f. of resistance just balances the applied e. m. f. and the electricity therefore moves uniformly. If the applied e. m. f. is made to disappear without otherwise altering the circuit the counter e. m. f. of resistance gradually reduces the current to zero or brings the electricity to rest.

Referring to the phenomenon of self-induction, Faraday says "The first thought that arises in the mind is that the electricity circulates with something like *momentum* or *inertia* in the wire." This idea, however, he soon gave up, but for inadequate reasons, as shown by Maxwell, whose treatment of the subject is based entirely on the idea of inertia. To set electricity into motion an e. m. f. is required just as a force is required to accelerate matter; and to bring electricity in motion to rest an opposing e. m. f. must be applied, just as an opposing force is required to reduce the velocity of a moving body. In strictness it is quite as improper to speak of an "electromotive force of self-induction" as of a "force of inertia" in dynamics. Failure to realize this has given rise to a great amount of confusion in electrical literature.

The fundamental self-induction relation in electric circuits is that of Faraday and Neumann: To alter the current in an electric circuit, and therewith the corresponding magnetic flux, an e. m. f. equal to the rate of increase of the flux must act in the circuit.

While a vast amount of progress has been made in measuring the quantities involved in self-induction and in studying the relations of other phenomena to those of self-induction, it appears that the only really fundamental progress made since the early days has come from studying the behavior of free electrons and other ions accelerated by electric and and magnetic fields. Well-known experiments by J. J. Thomson, Kaufmann, Bucherer, Hupka and others have yielded important information on the constitution of the electron and of matter; but it is unnecessary to do more than mention these experiments here.

Along with these experiments should be mentioned the experiments suggested by Maxwell[4] on the electric displacement produced in conductors by their mere acceleration. If a conductor is accelerated, since some of the electrons or other ions are free, an electric displacement would, in general, be expected to result.

Such effects in electrolytes have been observed by Colley,[5] Des Coudres,[6] and others; and after having been looked for in metals by Maxwell, E. F. Nichols,[7] and Lebedew[8] have been observed and carefully measured in a beautiful investigation by Tolman and Stewart.[9] The behavior of the electricity in a circular coil of wire which has been rotating about its axis and is quickly brought to rest as in these experiments, is very similar to that in a coil which has been carrying a steady current when the applied e.m.f. is reduced to zero without altering the resistance.

4. Faraday's experiments of group I. on conductors prove that when a rigid circuit moves in a fixed magnetic field there is produced around it an e. m. f. equal to the rate of diminution of magnetic flux through it, or the net rate at which it cuts across magnetic flux, with proper respect to signs. The two statements are equivalent, since tubes of magnetic induction are always closed. The second form is the more fundamental, as will be evident from what follows.

Similarly, the motional e. m. f. along any part of the circuit, or any line in any conductor moving in a magnetic field, is equal to the rate at which it cuts across magnetic flux.

On the electron and ionic theories of matter this is accounted for by the Ampèrian force

$$F = e\,[v\,H] \qquad \textbf{(1)}^{10}$$

which acts on any electrified particle of the matter with charge e moving with velocity v in a field of strength H. For this gives a motional intensity, or force per unit charge,

$$f = F/e = [v\,H] \qquad \textbf{(2)}$$

The integral of this intensity along any path in the conductor gives the result stated above.

Every experiment made since Faraday's time has confirmed this result. The most precise experiments are probably those which have been made in determining resistances in absolute measure by the method of Lorenz.[11]

In certain cases where different magnetic fields are superposed care must be taken to use for H in (2) the intensity of the field due to the fixed circuits or magnets with reference to which V is determined. An interesting illustration is that of an insulated wire inside a coaxial iron tube moving together with the wire across an (originally) uniform magnetic field due to fixed circuits or magnets. The e. m. f. developed in the wire is precisely the same as if the tube were absent, although the (resultant) field within the tube is greatly weakened by its presence. Since the tube moves with the wire the field due to its magnetization is not effective.

5. If non-conducting matter also is electrically constituted and moves in a magnetic field, each moving electrified constitu-

ent must, as in the case of a conductor, be acted upon by a force in accordance with (**1**), and thus by the motional intensity f given by (**2**).

Similarly, if the aether is electrically constituted, and if it moves in a magnetic field, it also will be the seat of a motional intensity given by (**2**).

The motional intensity will act to produce opposite displacements of the positive and negative constitutents of insulators as well as of conductors. This will, in general, give rise to an electric field, and the intensity E of this field will act on all electrical media which the field contains, whether at rest or in motion.

If both the aether and the matter which it permeates move together, as they do on the theory of Hertz,[12] both intensities act on both substances. But if the aether remains fixed, and the matter which it permeates moves through it, as on the theory of Lorentz[13], the intensity f acts on the matter only, while the intensity E acts on both aether and matter.

The motional intensity f, being equal to $[v\,H]$, is entirely independent of the nature of the moving substance provided only it has an electric constitution.

6. Referring to the matter of motional displacement, or electric displacement produced by the motional intensity, and to the displacement produced by the induced intensity, in insulators, Faraday says[14], "I have long thought there must be a particular condition of such bodies corresponding to the state which causes currents in metals and other conductors; and considering that the bodies are insulators one would expect that state to be one of tension. I have by rotating non-conducting bodies near magnetic poles and poles near them, and also by causing powerful electric currents to be suddenly formed and to cease around and about insulators in various directions, endeavored to make some such state sensible, but have not succeeded. Nevertheless, as any such state must be of exceeding low intensity, because of the feeble intensity of the currents which are used to induce it, it may well be that the state may exist, and may be discoverable by some more expert experimentalist, though I have not been able to make it sensible."

7. An imaginary experiment on this subject and unipolar induction combined was described by Poincaré in 1900[15]. But the first actual experiments after Faraday appear to be those of

Blondlot in 1901 on air[16]. In 1902 I began an investigation which included experiments on ebonite, sulphur, and rosin, but the work was not completed until 1908[17]. In the meantime H. A. Wilson[18] published an investigation on ebonite.

8. The essential theory of all these experiments can be given very simply. Consider an insulator in the form of a hollow circular cylinder with dielectric constant K rotating uniformly about its axis in a uniform magnetic field with intensity parallel to this axis. Suppose the inner and outer surfaces of the cylinder covered with conducting armatures of negligible thickness.

Let the number of revolutions per second be denoted by n, the magnetic flux across a right section of the space between the cylinders by φ, the capacity of the cylindrical condenser so far as it depends on the field between the armatures by $K\,C$, the capacity dependent on the field between the outer armature (together with any fixed conductors attached thereto) and the surrounding conductors, connected by a brush to the inner armature, by C'.

Let J denote the dielectric constant of that portion of the dielectric which moves. If the matter alone rotates while the aether remains fixed, $J = K - 1$. If the aether also moves, $J = K$. If the aether rotates alone, $J = 1$. It is clearly immaterial whether the armatures, which cut no magnetic flux, remain fixed or move.

When the cylinder is set into rotation the motional intensity f and motional e. m. f. $\Psi = n\,\varphi$ will act radially, let us say outwardly for definiteness, on the portion of the dielectric which moves. The electric separation produced in this part of the dielectric will give rise to an electric field whose intensity will be directed radially inward within the insulating cylinder and in which there will be a potential difference V directed from the outer armature to the inner armature, and from the outer armature to the surrounding conductors.

The total charge on the outer conductor and its connections, if any, will be zero, since it is completely insulated from the inner conductor and its connections. This charge consists of three parts superposed:

1. A charge $q_1 = - n\,\varphi\,J\,C$ **(3)**
on the inner surface;

2. A charge $q_2 = K\,C\,V$ **(4)**
on the inner surface;

3. A charge $q_3 = C' V$ **(5)**

on the outer surface and any conductors connected therewith. Since

$q_1 + q_2 + q_3 = 0$, we get, if $q_2 + q_3 = q_4$,

$$q_4 = (K\,C + C')\,V = n\,\varphi\,J\,C = -\,q_1 \qquad \textbf{(6)}$$

In Wilson's experiments and my own, hollow insulating cylinders were used, and the experimental processes (considerably different in the two investigations) were equivalent to measuring q_4, n, φ, and C and therefrom calculating J, which was found equal to $K - 1$ within the limits of the experimental error.

In Blondlot's experiments a parallel plate condenser (a special case of a part of a hollow cylinder) was used, and a swift stream of air was sent between the plates while they were connected together by a wire at rest, thus making V zero and leaving the motional e. m. f. Ψ to act alone. The connection between the plates was broken when the velocity of the air stream was a maximum, and the quantity q_1 directly measured. It was found to be zero, thus showing that $J = K - 1$, since K for air and aether together is practically unity.

All these investigations thus confirm the theory of Lorentz, according to which the aether is at rest. The results would be identical if there were no aether.

9. The field inside the rotating cylinder is of great interest, but can be discussed here for a few cases only. The solid cylinder rotating about its axis and the parallel plate moving parallel to one surface are particular cases of the hollow cylinder.

(1) First suppose the aether to be at rest and suppose the thin armatures either not existent or else disconnected from all other conductors.

In this case the total electric displacement D at all points of a cylinder of any radius $r \geqq r_1$ (radius of inner surface) $\leqq r_2$ (radius of outer surface) coaxial with the surface of the insulating cylinder is

$$O = D = \frac{1}{4\,\pi}\,\{\,(K - 1)\,f + K\,E\}$$

$$= \frac{1}{4\,\pi}\,\{K\,E + (K - 1)\,\omega\,H\,r\} \qquad \textbf{(7)}$$

where $\omega = 2\pi n$. Hence

$$E = -\frac{K-1}{K} f = -\frac{K-1}{K} \omega H r \qquad (\mathbf{8})$$

There is no intensity of either kind inside the inner cylinder or outside the outer cylinder.

(2) Next suppose the armatures present and connected by a wire at rest. This connection reduces the voltage $\int E\,dr$ to O, but the field intensity E does not vanish except over one cylinder of radius r_0 to be determined. If it did, the charge on the outer armature would be greater than the opposite charge on the inner, and the insulator itself would be internally charged. For f increases proportionally with r, and D would now therefore increase in the same way. The voltage through the insulator being zero, the direction of the field intensity E, always radial, changes in sign at the cylinder of radius r_0. Within this cylinder E has the same direction as f, so as to increase the total displacement; while outside this cylinder it has the opposite direction, so as to decrease the displacement which would exist were f alone acting. In this way the electric flux across all cylinders which can be drawn between the armatures is kept the same and equal to that across the cylinder of radius r_0. At the cylinder of radius r the field intensity is

$$E = -\frac{K-1}{K} \frac{\omega H}{r} (r_0^2 - r^2) \qquad (\mathbf{9})$$

while r_0 is given by the expression[19]

$$\left(\frac{r_2^2 - r_1^2}{2 \log \frac{r_2}{r_1}}\right)^{\frac{1}{2}}$$

(3) If the wire moves with the armatures a field intensity due to the potential difference V from the outer to the inner armature equal to the e. m. f. $n\,\varphi = \frac{\omega H}{2} (r_2^2 - r_1^2)$ developed in the wire will be superposed on the intensity given by (**9**), with the result that the displacement within the rotating condenser will be exactly the same as if it contained aether only, at rest, and were charged to the potential difference V[20].

(4) If the aether moves with the matter in case (1), we

must substitute K for $K - 1$, and we get in place of (**7**) and (**8**) the relations

$$O = D = \frac{1}{4\pi} K (f + E) \tag{10}$$

and $$E = -f = -\omega H r \tag{11}$$

Neither matter nor aether is displaced, either within or without the cylinder.

(5) If the aether moves with the matter in case (2), equation (**9**) becomes

$$E = -\frac{\omega H}{r} (r_0^2 - r^2) \tag{12}$$

while r_0 remains unchanged.

(6) If the wire moves with the aether and the matter of case (4) [or if the aether moves with the matter and the wire of case (3)], there is no displacement anywhere, exactly as in case (4), where the wire was absent[21].

10. In the second group of experiments Faraday found that if a conducting circuit was kept fixed and the magnetic flux through it altered in any way by the motion of adjacent circuits or magnets, an e. m. f. was developed around it equal to the rate of decrease of magnetic flux through it, precisely as in the experiments of the first group for the same relative motion of the material systems. In this case the tubes of magnetic induction, which are always closed, must be conceived to move across the circuit, and the intensity induced therein at any point may be conceived as given by the expression

$$E = [\mathbf{H}\, v] \tag{13}$$

where v is the velocity of the tubes. The electromotive force around the circuit is the line integral of this expression.

Furthermore, if the conducting circuit is kept fixed, as before, and the magnetic flux through it changed in any way by the alteration of adjacent magnets or circuits, or currents in these circuits, an e. m. f. is developed and is equal, again, to the rate of decrease of magnetic flux through it. In this case also we may conceive the (closed) tubes of magnetic induction to move across the circuit, producing therein at any point an intensity given by (**13**).

If the circuit is not conducting, but is merely a path drawn in an insulator or in the free aether, the electromotive force around it and the electric intensity at any point of it are given by the same expressions as before. The displacement, the effect of the intensity, of course differs with the conditions.

There is never any essential difficulty in determining the induced e. m. f., or line integral of the induced intensity, around a complete circuit from the Faraday-Neumann law; but the application of equation (**13**) to the determination of the intensity at a point is often impossible. For, except in very special cases, we do not know the velocities of the tubes of induction. Indeed, in certain cases the very conception of the motion of tubes of induction appears to many to be without meaning.

Consistently with experiment, however, the theory has been put in such a form by Maxwell, Clausius, and Lorentz, as to give for the induced intensity at a point, an expression which depends only on the motion of the electrons which produce the magnetic field and the time.

If e_1 denotes the (fixed) charge of a certain electron, r_1 its distance from the point P at which the induced intensity is to be determined, and $\mathbf{v}_1$ its velocity, then at the time t the vector potential at P due to this electron is by definition,

$$A_1 = \frac{e_1\,\mathbf{v}_1}{r_1}$$

the (changing) quantities $\mathbf{v}_1$ and r_1 being the velocity and distance at a time earlier than the time t by the interval required for an electric wave to travel from the electron to P. The vector potential A at P due to all the moving electrons is the vector sum of all the minute vector potentials $A_1 = \frac{e_1\,\mathbf{v}_1}{r_1}$

$A_2 = \frac{e_2\,\mathbf{v}_2}{r_2}$, etc. That is $A = \text{vector} \sum A_1 = \text{vector} \sum \frac{e_1\,\mathbf{v}_1}{r_1}$

In terms of this vector potential A the expression for the induced intensity is simply

$$E = -\frac{d\,A}{dt} \qquad (\mathbf{14})$$

and the electromotive force around the circuit is the line integral of this expression. Even in cases where it is not possible to determine the velocities of the electrons and thus calculate A, it is possible to determine whether A, and thus also $\frac{dA}{dt}$, changes when certain variations in conditions occur, and thus to obtain useful information with respect to E.

11. In many cases the magnetic field in which a body is moving is changing with the time, and we have the motional and induced intensities superposed. Similarly, they are superposed when the body under experimentation and the agent producing the field are both in motion.

If the system referred to as fixed is, instead of being fixed to the earth, fixed to a ship or car in uniform motion, there is no difference in observed results, according to experiments hitherto made. It is understood that the observer and instruments are on board, though this is often a matter of no consequence.

It will be instructive to consider some simple experiments, in part made familiar long ago by Faraday, with a circular cylindrical magnet A and an adjacent coaxial circular coil of wire B with a remote galvanometer connected into the circuit by long twisted leads.

(1) If A is fixed to the earth and B moves along the axis, there will be a motional e. m. f. in B and a certain electric charge q will traverse the galvanometer for a given change of magnetic flux through B. (2) If now B is fixed to the earth, and A is displaced, the relative motion of A and B being the same as before, there will be an induced e. m. f. in B exactly equal to the motional e. m. f. in the previous case, and the same charge q will traverse the galvanometer.

It is of no consequence whether the galvanometer is attached to A, or to B, or to the earth. The indications will be the same, and will appear the same to observers on A, or in B, or on the earth.

Suppose now that the region in which the experiments are performed is permeated by the aether, and for simplicity suppose this fixed relatively to the earth.

When experiment (1) is performed, the only electric intensity and displacement produced will be the motional intensity and displacement in the coil.

When (2) is performed, there will be the same displacement in the coil, due to an induced intensity equal to the previous motional intensity; and at the same time the field about the coil and magnet will be filled with circular lines of induced intensity all coaxial with the magnet and due to the motion of its tubes of magnetic induction. This induced intensity will produce electric displacement in the aether, the lines of displacement also being coaxial with the magnet.

The galvanometer shows no difference between the two cases, but the difference really exists.

If there is no aether, no electric displacement, aside from the current in the coil, will occur in either case.

If an experiment takes place in which relative motion between *A* and *B* occurs in an isolated region, and observers are placed on *A* and *B*, each observer is likely to assume that he is fixed and that the other is moving. The observer on *A* will conclude that there is a motional e. m. f. in *B*; while the observer on *B* will observe the same e. m. f. but will call it *induced.* A third observer, fixed to neither *A* nor *B*, will consider the e. m. f. to be partly induced and partly motional.

12. Faraday, as we have seen, attempted to study the displacement produced in insulators by the induced intensity, but without success. Except for a qualitative experiment of Hertz's[22] made with high-frequency oscillations and lying outside the scope of this discussion, no successful experiments on the displacement in material media appear to have been made. Kuehne[23] has, however, shown that a finite electrified body in a region traversed by moving tubes of magnetic induction is acted upon by a force consistent with equation (**13**).

13. Recently, in an investigation presented to the Physical Society, I tried to find out whether, in a certain special case, the induced intensity produces electric displacement in the aether.[24] But I expressed to the society a doubt, which still persists, as to the validity of one of the assumptions underlying the method. The experiment will be briefly considered.

14. Suppose an air condenser, with horizontal plates *A B*, short-circuited by a wire *C* and placed in a uniform magnetic field whose lines of induction are parallel to the plates. Suppose that the condenser is screened (an absolutely essential precaution) by being placed symmetrically within a metallic box whose faces are parallel and perpendicular to the plates, and that the upper plate is connected to the top of the box by a wire *F*.

If the box and condenser move together in the magnetic field parallel to the plates and perpendicular to the lines of induction, the plates will become charged, but the charge on the lower face of each plate will be equal and opposite to the charge on the upper face of the same plate. If during the motion the lower plate is removed and tested for total charge, it will thus be found uncharged.

15. If the box and condenser remain fixed and the magnet is moved, the charges will be exactly as before on the hypothesis that there is no aether. If the aether exists, however, there will be no electric displacement anywhere within the box, and the plates will be without charge on either side. The test of the lower plate for total charge will thus give the same result as before, and the experiment will not discriminate between the two hypotheses.

16. Imagine the magnetic field to be sharply divided into two parts by the plane passing through the upper surface of the lower plate *B*, the complete field throughout the region occupied by the box remaining uniform, but the tubes of induction of the lower part remaining fixed like the condenser, while the tubes of the upper part move when the magnet moves. In the attempt to accomplish this end I used two similar magnets, symmetrically placed with respect to the plate *B*, the lower one fixed to the condenser.

If this arrangement secures the end desired, and the condenser remains fixed while the upper magnet moves, the result will be different according to the hypothesis made with regard to the aether.

If there is no aether the upper surface of the lower plate of the condenser will become charged, there being now no intensity or displacement beneath the lower plate. If the aether exists, the plate will be uncharged.

Experiments made in this way have shown that the lower plate of the condenser does not become charged when the upper magnet moves.

If, however, the assumption made above with reference to the division of the magnetic field and the application of equation (**13**) under these circumstances are not justified, and the principle of superposition holds in such a way that the two magnets independently produce their individual effects, the lower magnet will produce no effect (at the critical time) and the upper magnet will act exactly like the single magnet of Sections 14 and 15 (but with a non-uniform field, which does not affect the theory essentially), producing no (total) charge on the lower plate on either hypothesis. This is the result to be expected from the application of equation (**14**). In this case the experiments simply confirm Section 15.[25]

17. We come now to the subject of unipolar induction.[26] In one of Faraday's experiments a symmetrical magnet rotating uniformly about its axis was touched by a wire *A C B*, including the coil of a galvanometer, at two points *A* and *B*, one near the axis at one end, the other on the cylindrical surface near the center. An e. m. f. was developed in the circuit equal to that which would be developed if the magnet remained fixed and the conductor *A C B* moved, the relative motion being the same as before.

In another experiment a copper disc was mounted coaxially close to one end of the magnet and a galvanometer *C* connected to two points *A* and *B* near the center and edge of the disc. When the disc rotated, and e. m. f. equal to that which would be produced by the same relative motion of *A C B*, was developed as before, whether the magnet rotated or not. But no current traversed the galvanometer when the disc remained fixed.

Similar results are obtained when the magnet is replaced by an electromagnet or by an electric coil wound on a non-magnetic core.

18. Faraday considered his experiments to prove that the tubes of magnetic induction remain fixed and that the magnet and disc move through them, the e.m.f. thus being a pure motional e.m.f. with the disk or the magnet itself as its seat.

It was pointed out by Tolver Preston,[27] however, that the results are equally well explained by the assumption that the tubes of magnetic induction share the rotary motion of the magnet and produce an induced e. m. f. by cutting the conductor *A C B*.

19. Faraday's experiments have been repeated with various modifications a great many times, but the problem of the seat of the e.m.f. was brought no nearer to a solution until the experiments of E. Lecher were published[28] in 1895. Lecher made three beautiful experiments, two of which, at least, are quite difficult to explain except on the assumption that the tubes of magnetic induction remain fixed, or that the seat of the e. m. f. is in the moving part of the circuit.

In one of these experiments, for which alone we have space, two similar electromagnets were mounted coaxially and near together, with the current in both coils in the same direction. A galvanometer was connected in the usual way to two points on one of the magnets. It was found that the current depended entirely on the motion of this magnet, being the same whether the other magnet rotated in either direction or remained at rest. On the assumption that the seat of the e. m. f. is the moving magnet the explanation of this result is quite obvious. Improbable assumptions are necessary to explain it on the other hypothesis. By making sufficient assumptions however, this is possible; and Lecher did not consider his experiments *entirely* conclusive.

20. Many students of physics have thought that this problem could be solved by experiments on so-called open circuits—experiments in which static charges, or forces on bodies with such charges, would be looked for instead of permanent galvanometer currents. The list includes Weber, Tolver Preston, Hertz, Lodge, Lecher, and others.

Now, if we could assume that the aether does not exist, and also that tubes of magnetic induction moving in a region free from matter and aether produce no electric displacement (there being nothing there to displace), we should have to reach the conclusion that this idea is correct.

If, however, the aether exists and if it is electrically constituted, so that electrical displacement occurs in it when tubes of magnetic induction move through it (provided there is no neutralizing intensity of other type present), it can be shown that the electric displacement in the region about a rotating magnet is the same whether the tubes of magnetic induction move with the magnet or remain fixed.

21. As a particular case, consider a cylindrical air condenser placed in a uniform magnetic field with lines of induction parallel to its axis and short-circuited by a wire. If this cylinder, together with the wire, were rotated about its axis it would become charged by the motional e.m.f. in the wire, the charge of each armature being numerically equal to this e. m. f. multiplied by the capacity.

If, however, the condenser and wire remain fixed, and the agent producing the magnetic field rotates about the axis, the relative motion being the same as before, the result to be expected depends on the hypothesis made with respect to the aether.

First suppose that the aether does not exist. If the tubes of induction do not move, the condenser will remain uncharged. If the tubes of induction move with the agent, an e. m. f. will be induced in the wire producing a potential difference in the opposite direction through the condenser and charging it as when the condenser moved.

If, on the other hand, the aether exists, there will again be no charge in case the tubes of induction remain fixed. If the tubes of induction move, however, there will be superposed on the potential difference developed in the coresponding case for no aether an equal and opposite e. m. f. induced in the aether between the armatures. Thus there will be no displacement between the armatures. Also there will be no displacement inside the inner armature or outside the outer armature, the relative motion of the tubes of induction and the aether in these regions being exactly the same as in the case of Section 9, (7). Thus the system will remain uncharged, just as if the tubes of induction had remained fixed.

Thus if the condenser should become charged in such an experiment it would prove that the aether as an electrical medium does not exist, and that the tubes of induction move.

But if the condenser should not become charged, the experiment would prove only that either (1) the aether does not exist and the tubes of induction do not move, or (2) the aether exists.

22. In 1912 I completed an extended series of experiments of this kind, not with the hope (which I originally had) of solving the problem of unipolar induction, but to get what information they might yield on the relations between electromagnetic induction and relative motion.[29]

The experiments show that the condenser does not become charged, the experimental error being a small fraction of the charge the condenser would receive if it rotated while the agent producing the field remained fixed.

This is the first case in electromagnetic induction in which it has been proved that the observed effect does not depend entirely on the relativity of the motion of the essential material systems involved.

23. If the condenser and short-circuiting wire are made to rotate together with the agent producing the field, there will be superposed on the (zero) charge of the condenser in my experiments a charge equal to that it would take if the agent producing the field remained fixed and the condenser rotated.

Rotating the agent alone produces no charge; rotating the condenser and wire alone produces a charge. When both are rotated together the effects must be superposed.

This corollary of my experiments has been confirmed in each of two recent investigations; one by Kennard,[30] who had done earlier work in this field; and one by Pegram.[31]

In their experiments the apparatus was essentially similar to my own, but the condenser and coil were both made to rotate. The condenser was found to become charged in accordance with the theory.

In this last rotation experiment we have a positive effect of electromagnetic induction without any relative motion between the essential material parts of the system. In my own rotation experiments we have a zero effect with a positive relative motion. Neither group of experiments, however, appears to be inconsistent with the principle of relativity of Einstein, which relates to translatory motion only.

These experiments do not solve the old problem of unipolar induction. As shown above (Section 21) they prove *either* (1) that the aether does not exist and that the tubes of induction do not move, *or* (2) that the aether exists. If we had evidence that the aether does not exist, the experiments would prove that the tubes of induction remain fixed.

24. The *simplest* assumption which will account for all the unipolar phenomena is Faraday's assumption that the tubes of induction are fixed and that the e. m. f. is a pure motional e. m. f. in the moving conductors. The electron theory, moreover, supports this assumption in the simplest case to which it can be applied,[30] viz. that of a thin solenoid carrying a direct current and rotating about its axis. When the solenoid is rotated there is simply superposed on the conduction current density at any point of the solenoid a convection current density of identical nature and zero magnitude, since the positive and negative charges per unit volume of the conductor are equal. And this could not, apparently, affect in any way the state of the magnetic field.

For practical purposes, however, it is of no consequence which assumption is made. On the simpler hypothesis, the calculation of the e. m. f. may be made from equation (**2**); on the other, from equation (**13**); and on either hypothesis, or any combination of the two, it may be calculated from the rate of change of flux through the circuit from the brush *A* in contact with the cylindrical surface of the magnet, through the galvanometer to the brush B in contact with the center of the end surface of the magnet, from B to a point C fixed on the magnet in the same transverse circle with A, and from C along the arc of the circle to the brush A. With the uniform growth of the arc $A\,C$, which contributes nothing to the e. m. f. and may encircle the cylinder any number of times, the flux through the circuit changes at the same uniform rate on any hypothesis.

25. This arrangement, essentially the unipolar or homopolar generator, in which the rotation takes place about the axis of a symmetrical field and one part of the system cuts the flux uniformly and always in the same direction, is clearly the only one in which a steady direct current can be electromagnetically produced by rotation without commutation. With rotation about any other axis the e. m. f. will fluctuate or alternate periodically.

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Carnegie Institution of Washington.

FOOTNOTES

1. For recent general discussions of electromotive forces of induction see F. Emde, *Elektrotechnik und Maschinenbau* 26, 1908, pp. 997, 1023, 1074, 1119, and 27, 1909, p. 783; also de Baillehache, *Bull. Soc. Int. des Électriciens* 10, 1910, pp. 89, 288.

2. For a brief account of the work of some of the early investigators see Brillouin, *Propagation de l'Électricité*, pp. 159-167, 1904.

3. Much of the work prior to 1895 is described by E. Lecher, *Wied. Ann.* 54, 1895, p. 276.

4. Treatise, §§576, 577.

5. *Wied. Ann.* 17, 1882, p. 55.

6. *Wied. Ann.* 49, 1893, p. 284; 57, 1896, p. 232.

7. *Phys. Zeit.* 7, 1906, p. 640.

8. *Ann. d. Phys.* 39, 1912, p. 840.

9. *Phys. Rev.*, 8, 1916, p. 97; 9, 1917, p. 164.

10. The expression $[v\,H]$ signifies the *vector product* of the vectors v and H. Its magnitude is equal to the product $v\,H\sin\theta$, when θ ($<180°$) is the angle between the directions of the two vectors; and its direction is the direction in which a right handed screw would be translated if it were rotated through the angle θ from a position in which the slot in its head has the direction of v to that in which it has the direction of H. It is thus perpendicular to both v and H.

11. *Pogg. Ann.* 149, 1873, p. 251. The most recent and precise work on this subject is that of F. E. Smith, *Roy. Soc. Phil. Trans.* A. 214, 1914, p. 27. For some recent experiments on the motional e. m. f. in conductors, consistent, like all others, with equation (2), see C. Hering, TRANS. A. I. E. E. 27, 1908, p. 1341; and A. Blondel, C. R. 159, 1914, p. 674.

12. Electric Waves, p. 241 (*Wied. Ann.* 41, 1890, p. 369).

13. *Archives Neerlandaises* 25, 1892, p. 363.

14. Exp. Res. § 1728.

15. *L'Éclairage Électrique* 23, 1900, p. 41.

16. *J. de Phys.*, Jan. 1902.

17. *Phys. Rev.* 27, 1908, p. 425.

18. *Roy. Soc. Phil. Trans.* A., Sept., 1904.

19. Barnett, l. c., pp. 431-433.

20. Attention was first called in print to this result by E. H. Kennard (*Phys. Zeit.*, 13, 1912, p. 1156), though I had previously made use of it.

21. The capacity of the wire is here neglected. The wire itself, of course, becomes charged and there is displacement in the dielectric about it.

22. *Electric Waves*, p. 95.

23. *Phil. Mag.*, Apr. 1910.

24. *Phys. Rev.* 12, 1918, p. 95.

25. As another illustration of the great difficulty involved in getting information about the aether from experiments in electromagnetic induction it is instructive to consider the following: A long circular solenoid with an iron core is traversed by an alternating current, so that tubes of magnetic induction periodically move into and out from the core, producing circular lines of electric intensity centered on the axis. A long narrow, and thin air condenser is mounted near the solenoid with its greatest length and the planes of its armatures parallel to the axis. The armatures are connected by a wire which includes a detecting instrument. If there is no aether, the condenser receives alternating charges on the *inner* surfaces of its armatures; if the aether exists, the condenser receives the same charges, but on the *outer* surfaces of the armatures, the detecting instrument thus indicates the same current on both hypotheses. Essentially the same difficulty would arise in an experiment similar to that of Section 15, but made without an electric screen.

26. In addition to Lecher, l. c., see Barnett, *Phys. Rev.* 35, 1912, p. 323; G. W. O. Howe, *Electrician* 76, 1915, pp. 169, 210, 323, 355; and Pegram, *Phys. Rev.* 10, 1917, p. 591.

27. *Phil. Mag.* 19, 1885, pp. 131 and 215.

28. Lecher, l. c.

29. *Phys. Rev.* 35, 1912, p. 323.

20. *Phil. Mag.*, Feb. 1917.

31 Pegram, l. c.

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THE POSITIONS OF ATOMS IN METALS

BY A. W. HULL

ABSTRACT OF PAPER

When a narrow beam of X-rays passes through a fine powder of any crystalline material, it produces on a photographic plate placed just behind the powder a pattern of concentric circles. These circles are produced by the reflection of the X-rays from the planes of atoms in the crystal, and their diameters are a measure of the distances between these planes ofatoms. By measuring the diameters of the circles the exact positions of the atoms can be determined. The results of this analysis are given for twenty common metals and several salts, with examples and brief description of the method, and a discussion of the results.

THE determination of the exact positions of atoms in solid bodies is the next to last of a series of discoveries, that have made atoms as real as the bricks of which houses are built.

The atom of 20 years ago was the "hypothetical smallest subdivision of matter." The atom of today is a real object of definite shape and size. We know what it is made of. We know its weight in grams. We can see its splash when it impinges on a plate of fluorescent material. We know its exact speed when it flies about as gas. And, lastly, we know its exact position when it forms part of a solid body.

A brief enumeration of these discoveries is a necessary introduction to the following discussion.

First came the discovery of *dancing molecules.* Heat had been considered a substance. The "Kinetic Theory of Gases" proved that it is a condition, *viz.*, the motion of the molecules, which fly about like frenzied bees, bumping against each other and the walls of their enclosure. Through this discovery, all the store of facts and laws about gases can be correlated by the single picture of these dancing molecules. We believe in these dancing molecules as firmly as in the law of gravitation. Whenever we think of gas we see dancing molecules.

The next discovery was J. J. Thomson's *streaming electrons.* Our text-books taught, and some still do, that electricity is not a fluid, though it behaves in many ways like one. Thomson proved that electricity is a fluid, that its atoms are the electrons which constitute the atoms of matter, and that it flows through wires just as water flows through pipes.

Next came the *weighing of the atom.* Faraday showed long ago how to determine the weight of an atom in terms of the charge it carries in electrolysis. There remained, therefore, only the measurement of this "unit charge" *viz.*, the charge of a single electron, by Millikan, to give the exact weight in grams of any atom that can be deposited electrolytically. As soon as the weight of any one atom is known, the weights of all the others can at once be calculated from the known relative atomic weights.

Then came the *counting of individual atoms.* This began with Sir William Crookes' "spinthariscope," and culminated in the beautiful experiments of Rutherford and Geiger, in which they counted one by one the helium atoms (the so-called "α particles") as they emerged from the surface of disintegrating radium; and then allowed them to pass, one by one, into a thin-walled glass tube, until enough had accumulated to form a gas whose pressure could be measured and spectrum analyzed.

These counting experiments led directly to the determination of the *composition of the atom.* J. J. Thomson had proved that every atom contains electrons. Rutherford proved that it also contains a positively charged kernel or nucleus, very small compared to the whole atom, but so dense that it contributes nearly the whole weight of the atom. The hypothetical atom thus became a concrete thing that can be visualized; a tiny, (but large enough to be studied) solar system, with nucleus sun and electron planets. The only respect in which one kind of atom differs from another is the magnitude of the positive charge of the nucleus, which determines how many electrons it can hold in its planetary system, and hence all its physical and chemical properties.

Finally came the discovery, by the Braggs, of the method of determining the positions of the atoms in solid bodies. The beautiful "point lattices" of the crystallographers were hypothetical. They enumerated possibilities, but could not point out the reality. The Bragg measurements of atomic distances give the actual arrangements. They are as accurate and reliable as those of the surveyor or astronomer. The only assumption made is that the arrangement of atoms is a regular one which repeats itself, and this assumption can be checked by experiment. The method consists simply in the measurement, by means of a special "measuring rod" which will be described, of the distance between atoms in three or more different directions. From these measurements a model can be constructed, which can then be checked by further measurements. The model must also agree with known physical properties of the substance, such as density, atomic weight, and crystal habit. A model which contains but one kind of atoms and satisfies all these tests may be regarded as very reliable. The reliability is still further increased by the fact that all the models investigated thus far have turned out to be very simple. In cases where there is more than one kind of atom, *i.e.*, compounds or alloys, an additional factor, *viz.*, the size and shape of the atoms, must be taken account of. There is one type of compound, containing only two kinds of atoms, whose structure is so simple that it cannot be misunderstood. Examples of this type will be included in the following discussion. Compounds containing more than two kinds of atoms have not yet been sufficiently studied to warrant their discussion, but there is every reason to believe that their analysis will be equally simple and reliable.

In the following pages, there will be given, first, a general survey of the results obtained, then a brief description of the method of measurement, and lastly, a more complete discussion of the individual models and some of their properties.

I have referred to the location of atoms as next to last in the series of atomic discoveries. For in order to complete the picture, one more discovery is necessary, *viz.*, the shape and size of the atom. An excellent beginning in this direction has already been made by Langmuir[1] whose theory of atomic structure predicts the shapes and relative sizes of all the atoms, and gives strong chemical evidence in favor of these predictions. The author hopes soon to be able to add the evidence of X-Ray measurements, which will determine not only the shape but the exact size of the atoms, that is, the positions of the electrons in the atoms.

2. *Summary of Results*. The most striking result of these investigations is the extreme simplicity of arrangement of atoms in common metals. Among the metals thus far ex-

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1. Langmuir, *J. Amer. Chem. Soc.* 41, 868, June, 1919.
2. Hendrick, *J. Chem. Met. Eng.* 21, 3, July, 1919.

amined only three types of atomic arrangement are found, and these are, with one exception, the three simplest geometrical arrangements known. The simplest arrangement of all is not found among metals, but is characteristic of salts, which are composed of equal numbers of positive and negative ions. This type and a fifth type, also very simple, which is characteristic of non-metallic elements, will be included in the discussion for the purpose of comparison.

The most common arrangement in metals is the *face centered cubic* arrangement, shown in Fig. 1. This is also the most important since most of the useful metals,—*e. g.*, aluminium, nickel, cobalt, copper, silver, platinum, gold,—have this arrangement of atoms. Perhaps it would be better to say that

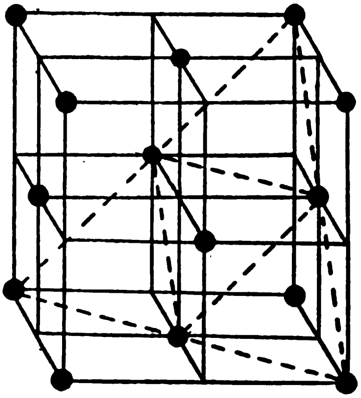

Fig. 1A—Face Centered Cubic Arrangement (Cubic Close Packing)

those substances are most useful as metals which have this arrangement, since, as will be shown later, their ductility is due largely to this arrangement.

The face-centered cubic arrangement is obtained by dividing the space occupied by a single crystal or "grain" of metal up into a system of equal, closely packed cubes (Fig. 1A) and placing an atom at each cube corner and at the center of each cube face. All the atoms in this arrangement, both corner and face atoms, are similarly situated as regards symmetry and relation to neighbors. Each atom is surrounded by twelve others, all equidistant and exactly similarly situated for every atom. It is this high degree of symmetry, combined with the close packing, that makes substances of this type so ductile. This arrangement is known as "cubic close-packing" and is one of the two alternative arrangements that equal hard spheres assume (Fig. 1B) when pressed tightly together, with sufficient shaking to allow them to find their places. This suggests, and the other evidence at hand points to the same

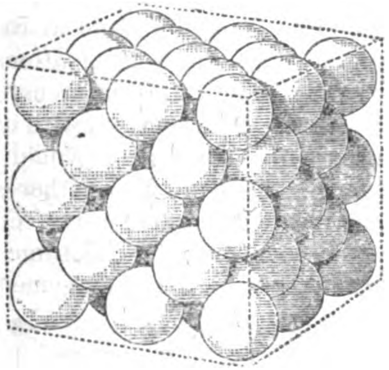

FIG. 1B—FACE CENTERED CUBIC ARRANGEMENT (CUBIC CLOSE PACKING)

conclusion,[2] that the atoms of the substances which have this arrangement are fairly spherical in shape. The necessary shaking corresponds to the temperature required for "annealing." The only difference between the packing of balls and

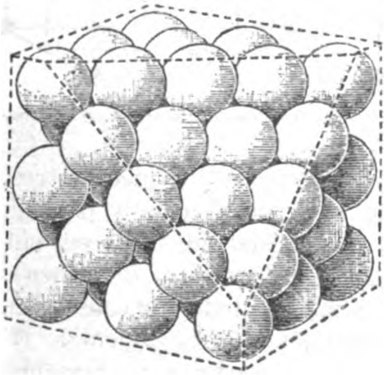

FIG. 1C—FACE CENTERED CUBIC ARRANGEMENT (CUBIC CLOSE PACKING)

that of atoms of this kind is the ability of the atoms to hold on to each other after they have found their places.

There is one important exception to the rule that the most ductile, and therefore the most generally useful, substances are those whose atoms are in face-centered cubic arrangement, *viz.*, iron. The atoms of iron, and also of chronium, molybdenum, tungsten, and the alkali metals, are in *centered cubic* arrangement (Fig. 2). This arrangement is obtained by dividing the space occupied by a single crystal or grain into equal close-packed cubes, and placing an atom at each cube corner and each cube center. The two sets of atoms, the "corner-atoms" and the "center atoms," are interchangeable, so that if the system of lines in Fig. 2 had started with one of the center atoms, all the corner atoms in Fig. 2 would become center atoms and vice versa. Each atom, whether center or corner atom, is surrounded by eight others in perfect cubic arrangement about it, situated always in the same direction and at the same distances. Hence this arrangement has the same high degree of symmetry as the face-centered cubic arrangement. It is not, however, as closely packed. Smooth, hard spheres cannot be packed in centered cubic arrangement except by the use of constraints, and when so packed are in unstable equilibrium. A slight jar causes them to reassemble in one of the close-packed arrangements. (Fig. 1 and 3) It is evident, then, that the atoms of these elements are either not spherical or that they possess some special forces of attraction localized at cube corners (see Fig. 15).

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[2] cf. Langmuir, l. c. p. 878.

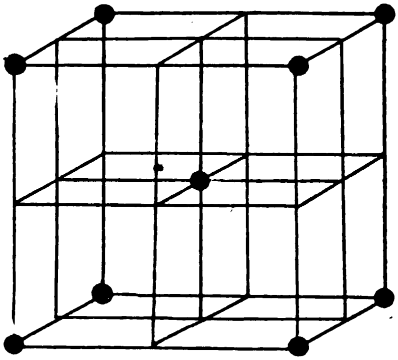


FIG. 3—CENTERED CUBIC ARRANGEMENT

The third type of arrangement found in metals is the *hexagonal close-packed* arrangement (Fig. 3). It is the second of the two alternative arrangements which equal hard spheres assume when closely packed by pressure and shaking. It is less symmetrical than the cubic close packed arrangement, but

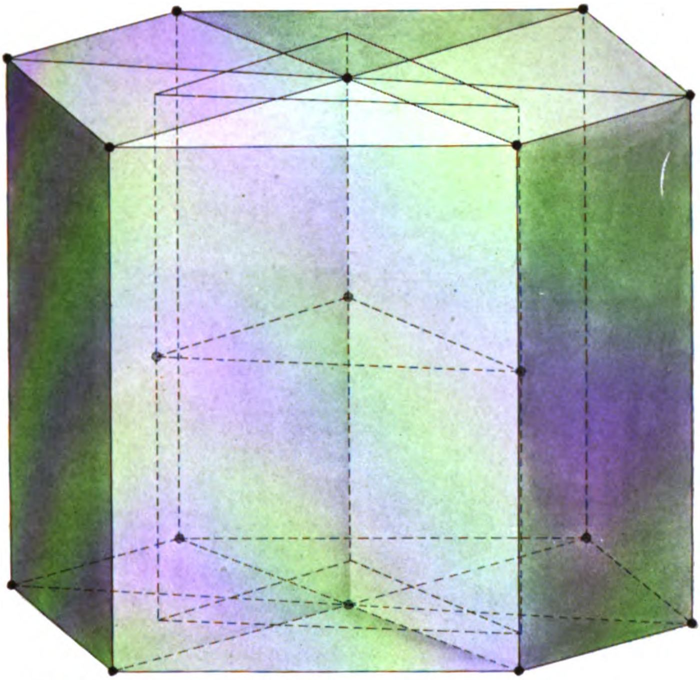
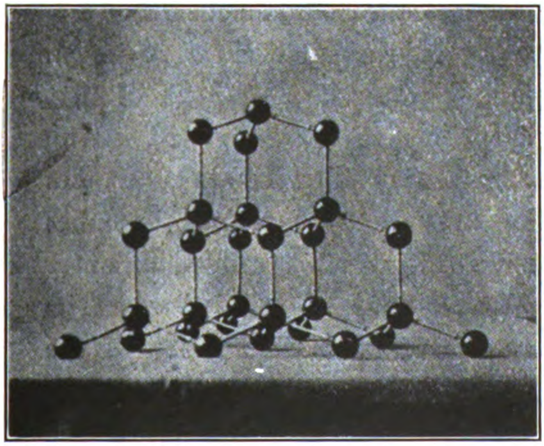


FIG. 2—HEXAGONAL CLOSE-PACKED ARRANGEMENT



[HULL]

FIG. 5—TETRAHEDRAL ARRANGEMENT

equally close packed. The two are closely related, and each can be produced from the other by a simple gliding, as will be shown later. This is the arrangement taken by the atoms of magnesium, zinc, cadmium electrolytic cobalt, and probably to some extent by all cubic close-packed metals when strained (so as to cause gliding.) This arrangement is formed by dividing the space occupied by a single crystal of the substance into a series of equal closely packed right triangular prisms, the bases of which are equilateral triangles, and the altitudes equal to 1.633 times the length of the sides of the triangles. (Fig.1A.) An atom is located at each prism corner and at half of the prism centers. This arrangement is simpler and more symmetrical than it appears. Each atom is surrounded by twelve others, all equidistant and uniformly spaced about it in dodecahedra arrangement. These dodecahedra are of exactly the same dimensions as in the cubic close-packed arrangement, but are not quite regular, the upper half being rotated 60° from the position corresponding to a regular dodecahedron.

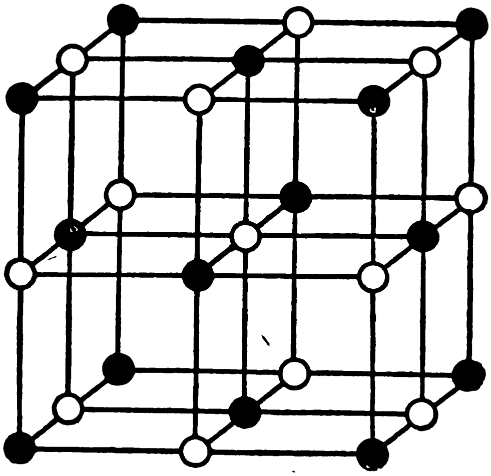


FIG. 4—SIMPLE CUBIC ARRANGEMENT

There are two other simple types of arrangement, which, though they do not occur among metals, are important for comparison, and their description will make clearer the distinguishing features of metals.

The first is the *simple cubic* arrangement (Fig. 4). It is formed by dividing the space occupied by a crystal into a series of equal, closely-packed cubes, and placing an atom at each cube corner. All the atoms are similarly situated, each being surrounded by six others, all equidistanct, in the direction of the cube faces. In spite of its great simplicity, it has only the same degree of symmetry as the two cubic arrangements already described. It is an extremely "loose packed" arrangement for hard spheres, and would be very unstable. A system of equal cubes, however, if packed in this manner would fill all space.

No elementary solid has yet been found whose atoms arrange themselves in this manner. This fact might be interpreted as evidence that none of the atoms are cubical in shape. There is strong evidence, however, that many of the atoms, especially those of low atomic weight, are approximately cubical in shape[3]. The fact that when these substances crystallize, their atoms do not pack together in simple cubic arrangement, is due rather to the nature of the forces holding them together (see discussion of iron, tungsten, etc., above.) It may be taken as evidence that these forces, in the case of cubical atoms, are not localized at the centers of cube faces, but at cube corners.

The substances which have this simple cubic arrangement of atoms are composed of equal numbers of positive and negative ions. The positive and negative ions alternate in every direction as shown in Figs. 4 and 16, so that each positive ion is completely surrounded by six negative ions and vice versa. The forces holding these atoms together are different from any of those thus far considered. In the cases described above, and in the great majority of compounds, the cohesion is due to the "stray fields" of the atoms. In these *ion compounds* it is due to the electrostatic attraction between the oppositely charged ions. This is stronger than the stray fields, and causes the atoms to pack together as closely as their shape will allow. The fact that they choose to pack in simple cubic arrangement is additional evidence that they are cubic in shape. No ion compounds of this kind, (*i. e.* containing equal numbers of positive and negative ions of approximately the same size) between spherical atoms have yet been examined, but it is to be expected that they will show one of the "close packed" arrangements (face-centered cubic or hexagonal) described above.

The fifth simple type of atomic arrangement is the *tetra-*

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3. (See Langmuir, l. c. 41, p. 892 ff.)

hedral arrangement. (Fig. 5.) Each atom is surrounded by four others, arranged in a regular tetrahedron about it. It is not as symmetrical as the three cubic arrangements described above (Figs. 1, 2, and 4) for while each atom is at the center of a tetrahedron of neighboring atoms, half of these tetrahedra are positive and half negative; *i. e.*, upside down with respect to the first.

The only substances thus far found with the tetrahedral arrangement of atoms are diamond, silicon, and the "ion compound" NH_4Cl. There is strong chemical evidence that in each of these substances, the unit of structure, (*viz.* the *C* and *Si* atom, and the NH_4 ion) is really tetrahedral in shape.

The Measuring Machine. The determination of these atomic arrangements requires the measurement, in as many different directions as possible, of the distance between consecutive ***planes of atoms.*** The arrangement of atoms, whatever it may be, is assumed to be a regular one which repeats itself throughout the crystal[5]. This assumption can be checked by the result. Through such an arrangement a system of equidistant parallel planes can be drawn in any direction whatever so as to pass through all the atoms. In most directions, these planes will be very close together and sparsely settled with atoms. In a few particular directions, however, they will be far apart and densely populated These are the directions of easy cleavage and gliding. It is these densely populated planes whose distances apart are measured.

The original measuring machine, by which the pioneer measurements were made, was a special form of "spectrometer." It has been simply and charmingly described by its inventors in a book[6] worth reading. The measurements described in this paper were made with a modified form of Bragg machine. The original machine was applicable only to large, perfect crystals, required careful manipulation, and was subject to serious error unless the crystals were very perfect and the number of observations large. The author's modification is free from these errors, requires but one simple observation, and is applicable to all substances which are crystalline, *i. e.*, all in which there is any arrangement to measure.

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[5] (If the arrangement is not regular, there is nothing to be measured. Such "amorphous" solids are very few in number, much fewer than was previously believed.)

[6] (W. H. and W. L. Bragg, "X-Rays and Crystal Structure" G. Bell & Sons, London.)

The complete machine is shown in Fig. 6. It consists of a small transformer (or other source of high potential) capable of supplying 1 kw. at about 30,000 peak volts; a Coolidge X-Ray tube, *X*; a thin sheet of properly chosen material, *f*, serving as filter; a pair of slits, s_1 and s_2, in metal sheets, to limit the beam of X-rays; a tiny glass tube, *T*, containing the powdered substance to be measured; and a photographic plate or strip of film bent in arc of circle, *F*. The operation consists in filling the glass tube with a few milligrams of the substance to be analyzed, powdered as finely as possible; "loading" the photographic film holder; exposing over night to X-Rays at 30,000 peak volts and as many milliamperes as the tube will carry safely without watching, (a maximum exposure of 300 milliampere hours); and developing the film.

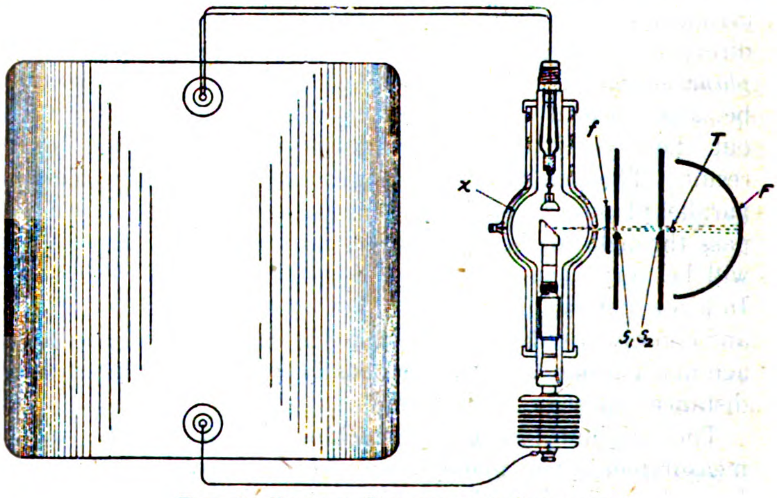

Fig. 6—Powder Photograph Apparatus

Typical photographs are shown in Fig. 7 A, and 7 B. Fig. 7A is a photograph of aluminium filings, taken with a plate and very short slits, so that the trace of the direct beam in the center of the plate is a circular spot. Fig. 7B is a photograph of molybdenum powder, taken with circular film and slits as shown in Fig. 6[7]. In this case the traces of the circles on the film show as nearly straight lines. The circles and lines are due to the

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[7] The central line and first "reflected" line in Fig. 7B have been partially absorbed by a "stepped" filter, placed directly in front of the film, for the purpose of measuring the intensity of the lines.

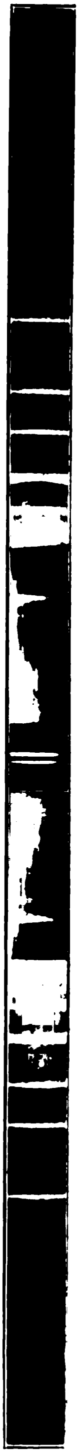
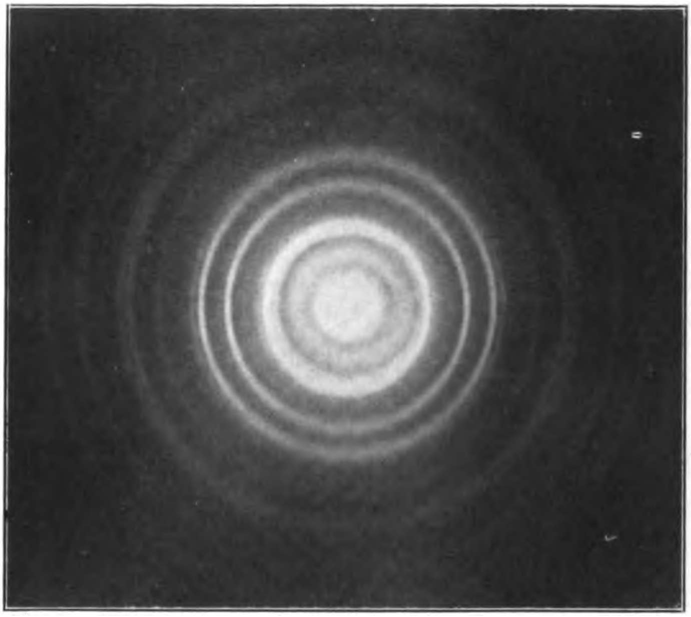


FIG. 7-B—MOLYBDENUM



[HULL]

FIG. 7-A—ALUMINUM

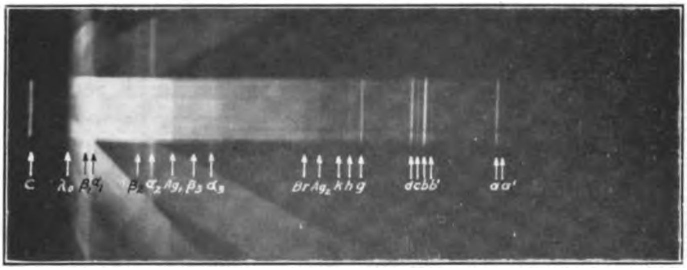


FIG. 8—X-RAY SPECTRUM OF TUNGSTEN

"reflection" of the X-rays by the tiny crystals of molybdenum in the tube, as will be described later. The distances of these circles or lines from the central line on the film are nearly proportional, inversely, to the distances between the planes of atoms, and from them these atomic distances can be easily and quickly calculated. Some examples of calculation are given below.

The Measuring Rod. The measuring rod by which these atomic distances are measured is the wave-length of a particular X-ray.

The possibility of measuring the dimensions of any physical body depends, primarily, upon the possession of a measuring rod of length comparable with the dimensions to be measured. Thus, the discovery and calibration of wave-lengths of visible light opened up a whole new field of measurements, comparable in length with this new measuring rod, such as the thickness of films, imperfection of polished surfaces, displacement of vibrating membranes, increase in length due to thermal expansion, etc. In the same way, the discovery that X-rays are of the same nature as light, and the isolation and calibration of X-ray wave-lengths, opened up a vast new field of measurements of dimensions comparable with the wave-length of X-rays; *viz.*, atomic dimensions.

We are accustomed to think of the measurement of things too large or too small to see and touch as necessarily very rough and approximate. It is somewhat of a surprise, therefore, to note that the only measurements accurate enough to justify the use of eight-place logarithm tables are those of astronomy; that wave-lengths of light are measured to 1 part in 10,000,000; and that the wave-length of X-rays, and by means of it, the distances between atoms, can easily be measured to 1 part in 100,000.

The spectrum of X-rays is exactly like that of visible light, except that the wave-lengths are shorter. It consists (Fig. 8) of bright lines superimposed upon a continuous spectrum. The wave-lengths in the X-ray spectrum depend upon anode material and voltage (Fig. 9 and 10) in exactly the same way that the wave lengths in the visible spectrum depend upon incandescent material and temperature. And just as it is possible to obtain nearly monochromatic yellow light by putting salt in a flame under proper conditions, so by running an X-ray

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8. (For a more detailed description, see Hull, *Phys. Rev.* 10, 666, 1917.)

tube with proper anode at the right voltage, it is possible to produce a single wave length (line) of such great intensity that practically all the rest of the spectrum can be absorbed by a properly chosen filter, leaving nearly monochromatic X-rays.[8] Fig. 10. It is in this way that the monochromatic X-rays used in these measurements are produced. The measurements described in this paper were made with X-rays from a molybdenum target operated at 28,000 volts constant potential, and the filter was powdered crystal zircon, pressed, with a small amount of organic binder, into a sheet ¼ mm. thick. The resulting spectrum, before and after filtering, is shown in Fig. 10.

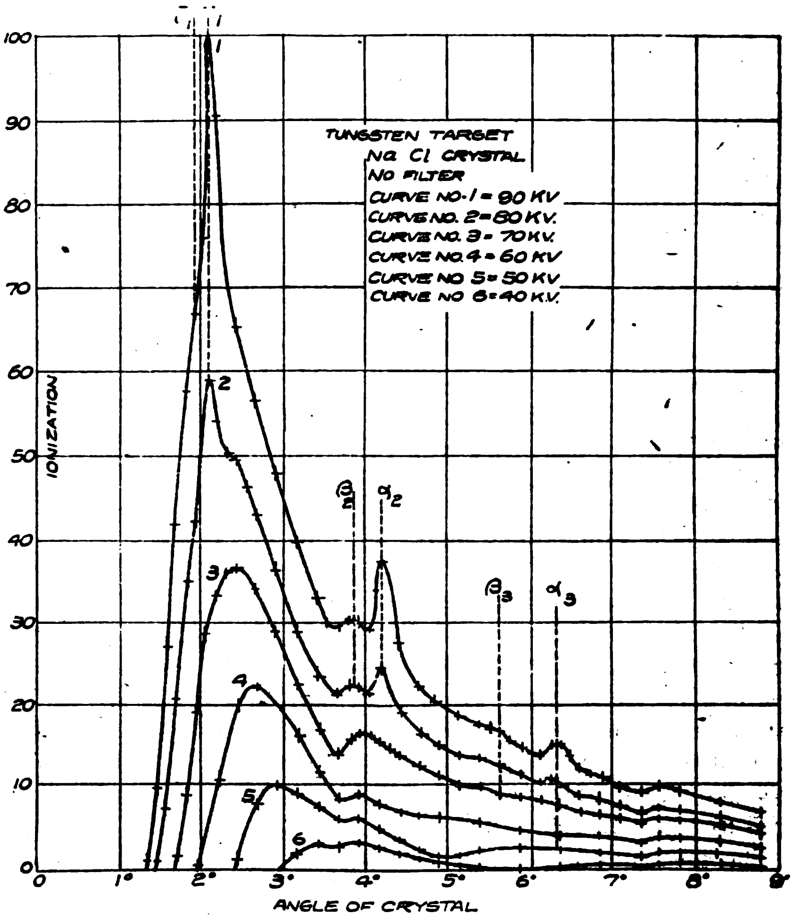

FIG. 9—EFFECT OF VOLTAGE ON X-RAY SPECTRUM OF TUNGSTEN

Calibration of Measuring Rod. The measurement of the wave-length of X-rays in centimeters was part of the pioneer work of the Braggs[9], and was accomplished in the same way as the measurement of visible wave-lengths, *viz.* by the use of a "grating" of known dimensions. It is interlocked with the determination of crystal structure, since the grating used was a crystal, and it was necessary, before using it, to determine its dimensions, *i. e.* the arrangement of atoms in it. The procedure was that of experiment and trial. Preliminary experiments indicated that the atoms of rock salt were in simple cubic arrangement, as shown in Fig. 4. Assuming this to be so, a rock salt crystal was used as a grating to measure tentatively the wave-lengths of X-rays. These wave-lengths were then used for further investigation of the arrangement of atoms in rock salt and other crystals, and were checked and corrected by successive trials.

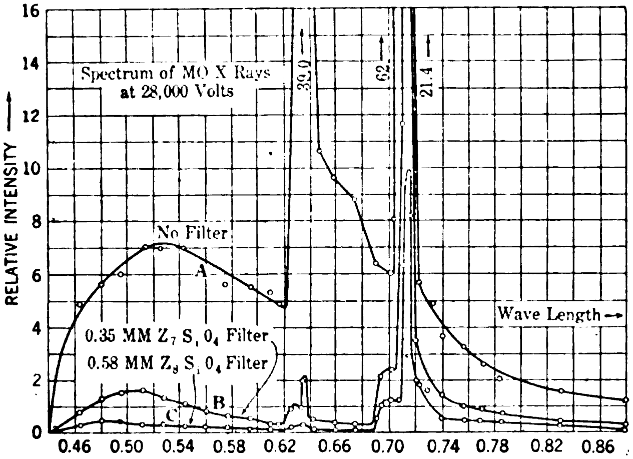

FIG. 10—EFFECT OF FILTERING ON MOLYBDENUM X-RAY SPECTRUM

The method of using the rock-salt grating is shown in Fig. 11. The crystal *C*, with its planes of atoms perpendicular to the paper, is placed in the path of a narrow beam of X-rays. Each plane of atoms acts like a mirror and reflects a small fraction of the rays. The reflection is a maximum when the reflected waves from all the planes (many million, except in the case of very long wave-lengths) are in phase, that is, when each is an exact wave-length or some whole number of wave-lengths behind the next. It is easy to show that this is true only when

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[9] X-Rays and Crystal Structure, p. 110).

$$n \lambda = 2 d \sin \theta \qquad (1)$$

where n is an integer, usually 1 or 2, λ the wave-length, d the distance between planes of atoms, and θ the angle of incidence (i in Fig. 11) of the rays on the crystal[11].

The determination of λ requires, therefore, the knowledge of n, d, and θ. θ can be observed, and the orders, n, counted. d must be determined initially from the physical properties of the crystal, *viz.* its density, atomic weights, and arrangement of atoms. This can best be explained by an example:

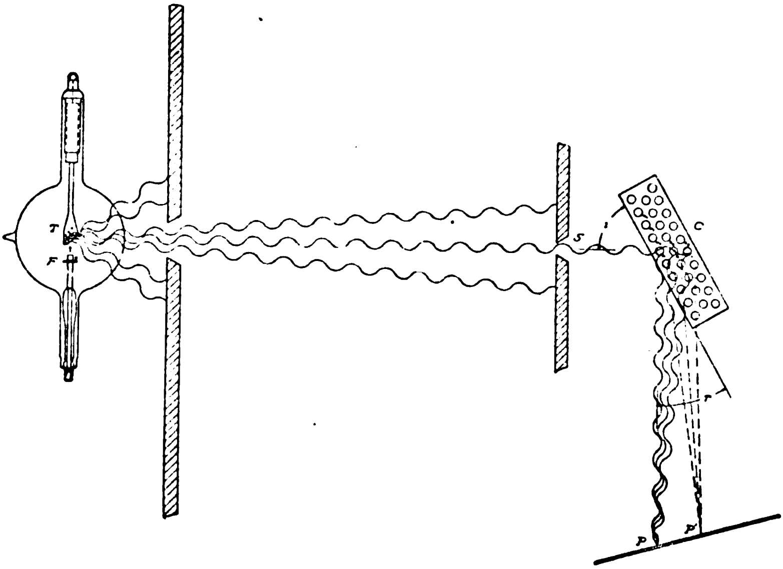

Fig. 11—X-ray Spectrometer

The atoms of rock salt are in simple cubic arrangement, as shown in Fig. 4. There is one atom to each cube, as can be seen by displacing all the atoms in Fig. 4 in the direction of a cube diagonal to the cube centers. Half of the cubes contain sodium atoms and half chlorine atoms. The average weight per cube is the mean of the weights of one sodium and one

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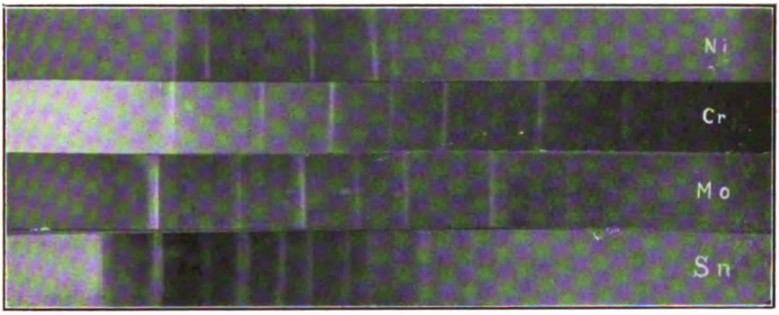
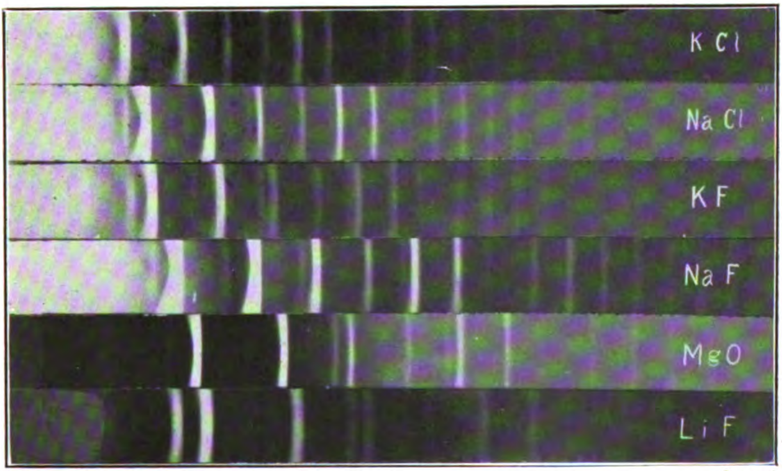
10. (It will be observed that in order to measure different wave-lengths the crystal must be rotated. This is the only essential difference between the crystal grating and the ordinary diffraction grating).



[HULL]

FIG. 12—TYPICAL X-RAY POWDER PHOTOGRAPHS OF METAL



[HULL]

FIG. 13—TYPICAL X-RAY POWDER PHOTOGRAPHS OF SALTS

chlorine atom, *viz.* $1/2\ (38.00 \times 10^{-24} g + 58.50 \times 10^{-24} g) = 48.25 \times 10^{-24} g$. Hence the density, which is the weight per unit volume, must be equal to $\frac{48.25 \times 10^{-24}}{d^3}$ where d is the side of one of the small cubes (Fig. 4,) *i. e.*, the distance between planes of atoms parallel to the cube faces. This value of density must be the same as that obtained by measuring and weighing a large crystal, *viz.* 2.174. This gives

$$d = \sqrt[3]{\frac{48.25 \times 10^{-24}}{2.174}} = 2.814 \times 10^{-8} \text{cm.} = 2.814\ \mathring{A}^{12}$$

The wave-length of the "$\alpha_0$doublet" of molybdenum determined in this way is $0.712\ \mathring{A}^{13}$. This is the "measuring rod" with which the following measurements were made.

Interpretation of Powder Photographs. The X-ray wave length thus calibrated can now be used to measure atomic distances. If, in the arrangement shown in Fig. 11, the X-rays are made monochromatic by proper voltage and filtering, then as the crystal is rotated a series of intense reflections will be observed at angles whose sines are in the ratio 1 : 2 : 3 etc., corresponding to successive integral values of n in Eq. 1. If a new face is ground on the crystal at an angle to the first, and exposed to the rays in the same way, another similar series of reflections will be observed, at different angles, corresponding to the different distance (d, Eq. 1) between the planes parallel to this new face. The process of analyzing a crystal consists in observing these reflections from as many faces as possible, and calculating, from Eq. 1, the distance between the planes parallel to them. When a single crystal is used this requires many observations. The work is greatly simplified by using a powder, in which all possible orientations are represented at the same time by one or more of the tiny crystals, and photographing simultaneously the reflections from all these little crystals. This is the method sketched in Fig. 6, and gives patterns of lines like Figs. 7, 12 and 13. It might be expected

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12. (The Angstrom unit or $\mathring{A}$ ($= 10^{-8}$ cm.) which is the standard unit for expressing wave-lengths of visible light, is even better suited to atomic and X-ray measurements. It will be used or assumed in all the following discussions).

13. (The best measurements of X-ray wave-lengths are those of Siegbahn, *Verh. Deut. Phys. Ges.* 13,300, 1917.

that the number of lines in these patterns would be infinite, since there is an infinite number of different possible planes in any crystal. The reflections from most of these planes, however, come at angles whose sines are greater than 1, (as is evident from equation (**1**) when d is small) and which therefore do not exist.[14]

The analysis of these photographs is very simple in the case of simple substances, like pure metals. It consists in finding, by successive trials, an arrangement of atoms whose planar spacings, beginning with the planes farthest apart and skipping none, exactly fit the observed pattern of lines. The calculation of the planar spacings for all the important planes is not difficult, and with simple substances but few trials are necessary.

The method of calculation can best be shown by an example. Potassium chloride (Fig. 13) gives the simplest pattern of lines yet observed. It consists of 6 regularly spaced lines, then a slight gap, then 7 more lines, (these may not all show in the reproduction), then another gap, etc. The best first guess is that a simple pattern like this corresponds to a simple cubic arrangement. The equation of solid geometry for the distance between planes in a simple cubic arrangement is

$$d = \frac{d_0}{\sqrt{h^2 + k^2 + l^2}} \qquad (\mathbf{2})$$

where h, k, and l are any whole numbers, and d_0 is the side of the cube. The numbers h, k, l, are called the "indices" of the planes. They are the reciprocals of the intercepts of the planes on the X, Y and Z axes respectively.

The largest distance is $\frac{d_0}{\sqrt{1}}$, corresponding to the "indices" 1, 0, 0. This gives the line nearest the center (see equation **1**). The next line is $\frac{d_0}{\sqrt{2}}$, given by the planes whose indices are 1, 1, 0. Then follow $\frac{d_0}{\sqrt{3}}$ (1, 1, 1), $\frac{d_0}{\sqrt{4}}$ (2, 0, 0), $\frac{d_0}{\sqrt{5}}$ (2, 1, 0), and $\frac{d_0}{\sqrt{6}}$ (2, 1, 1). The next line, corresponding to $\frac{d_0}{\sqrt{7}}$, should be lacking, as there are no three numbers the sum of whose squares is 7. Fig. 13 shows that it is actually lacking. Then follow, in regular order, $\frac{d_0}{\sqrt{8}}$ (2, 2, 0), $\frac{d_0}{\sqrt{9}}$ (2, 2, 1 and 3, 0, 0), $\frac{d_0}{\sqrt{10}}$ (3, 1, 0), $\frac{d_0}{\sqrt{11}}$ (3, 1, 1), $\frac{d_0}{\sqrt{12}}$ (2, 2, 2), $\frac{d_0}{\sqrt{13}}$ (3, 2, 0) and $\frac{d_0}{\sqrt{14}}$ (3, 2, 1). Then should come another gap, corresponding to $\frac{d_0}{\sqrt{15}}$, which cannot be formed from the squares of three integers. These regularities can be better seen in some of the other patterns in Fig. 13, which are exactly similar to that of $K\,Cl$, except that there are extra lines just in front of the first, third and fifth regular lines due to the difference in weight and size of the two atoms of which these salts are composed. The calculation of the positions of these extra lines is also simple, but will not be given here.

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[14] (This means physically that there is no angle of incidence large enough to make the reflection from one plane a whole wave-length behind that from the one in front.)

Returning to $K\,Cl$, the positions of the lines calculated from the above series of inverse square roots are found to coincide exactly with the observed pattern. This proves that the first guess was correct, that the atoms of $K\,Cl$ are in simple cubic arrangement. The result can be independently checked, however, by the density. For the average mass in each of the small cubes, divided by the volume of the cube, must equal the known density of the substance. The value of d_0 calculated from equation 1 is 3.13 Å. The average weight of potassium and chlorine atoms is $\frac{1}{2}(64.5 + 58.5) \times 10^{-24}\,g = 61.5 \times 10^{-24}\,g$. This gives for the density $\frac{61.5 \times 10^{-24}}{(3.13 \times 10^{-8})^3} = 2.01$ which checks with the standard value within experimental error[15].

One more example may be briefly cited, *viz.* molybdenum. Its pattern is shown in Fig. 10. It is found that the series of lines which corresponds to a simple cubic arrangement does not fit this pattern. We therefore try a centered cubic arrangement. The distance between planes in this arrangement is calculated in the same way as for the simple cubic arrangement, except that half the lines, *viz.* those due to planes the sum of whose indices are odd, are lacking[16]. Hence the relative spacings, beginning with the largest, should be proportional to

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[15] (These X-ray determinations of density are, in general, much more accurate than the standard ones).

$\frac{1}{\sqrt{2}}, \frac{1}{\sqrt{4}}, \frac{1}{\sqrt{6}}$, etc. The series of lines calculated from these values is found to fit the pattern of Fig. 10 exactly. The length d_0 of the side of the small cube is 3.15 Å. As check, the density of molybdenum should be equal to the weight of two molybdenum atoms divided by the volume of the cube, *i. e.*

$$\frac{318 \times 10^{-24}}{(3.15 \times 10^{-8})^3} = 10.0 \text{ which is the correct value.}$$

DISCUSSION OF RESULTS

The results of the measurements that have been made thus far are summarized in the following table. The list includes most of the metals that are easily obtainable in pure form, a few simple salts, as examples, and the non-metallic elements carbon (diamond) and silicon. The structure of graphite is less simple, and will not be discussed here. It apparently contains a mixture of forms, produced by gliding, like cobalt.

The case of cobalt is exceptional. A finely powdered sample produced by rapid electrolysis showed a mixture of cubic and hexagonal close-packing in nearly equal ratio. After annealing in hydrogen at 600 deg. this sample showed only the cubic form. Another sample, composed of filings from pure cast metal, showed slight traces of hexagonal packing, due presumably to straining. It is probable that the other cubic close-packed metals will behave in a similar manner, but this question has not been studied.

PHYSICAL PROPERTIES

Many of the physical properties of these substances are evident from an inspection of their atomic models. Thus it is clear why metals with face-centered cubic arrangement are soft and ductile. For in the planes parallel to the octahedral faces (the bevelled face in Fig. 1c) the atoms are so closely packed that one plane can slip over the one beneath it without

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[16] (For details and theory see Hull, *Phys. Rev.* 10,673, 1917).

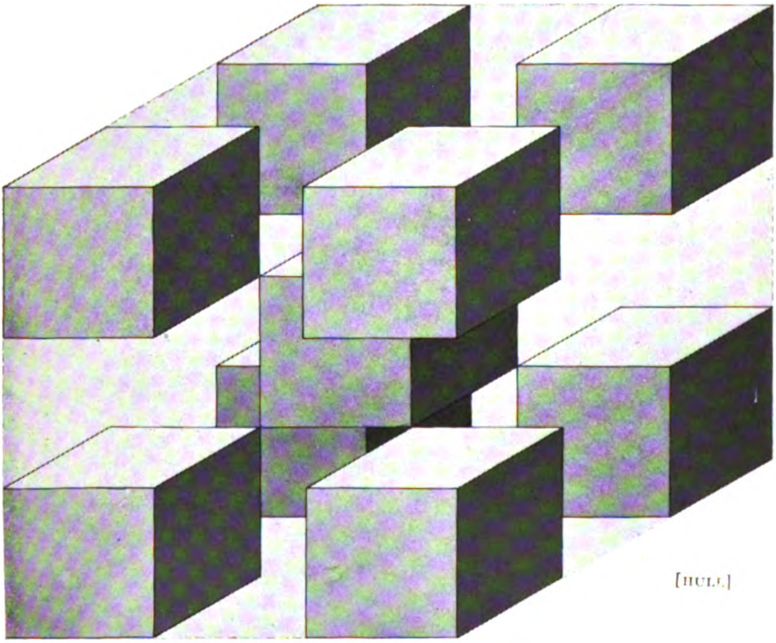

FIG. 15—PACKING OF ATOMS IN CENTERED CUBIC ARRANGEMENT

appreciable elevation, and without the atoms getting away from each other's attractive influence. There are 4 sets of planes parallel to which this easy gliding can take place, *viz.* those parallel to the 4 pairs of octahedral faces, and in each of these planes there are three equally easy directions. There is no direction, therefore, in which a shearing force can be applied to a crystal of this kind which would not be nearly parallel to one of these directions of easy gliding.

TABLE I.

Substance	Arrangement of atoms	Length of side of elementary cube in Ångstroms	Distance between nearest atoms (between centers) in Ångstroms
Aluminum	Face-Centered Cubic	4.05	2.86
Cobalt	(Cubic close-packed)	3.57	2.52
Nickel	"	3.54	2.50
Copper	"	3.60	2.54
Rhodium	"	3.82	2.70
Silver	"	4.06	2.87
Platinum	"	4.02	2.85
Gold	"	4.08	2.88
Lead	"	4.92	3.48
Lithium	Centered Cubic	3.50	3.03
Sodium	"	4.30	3.72
Chromium	"	2.91	2.52
Iron	"	2.86	2.48
Molybdenum	"	3.15	2.73
Tungsten	"	3.15	2.73
Magnesium	Hexagonal (close-packed)	..	3.22
Zinc	"	..	2.84
Cadmium	"	..	3.15
Cobalt	"	..	2.53
Diamond	Tetrahedral	3.56	1.54
Silicon	"	5.43	2.35
Lithium Fluoride	Simple Cubic	2.01	2.01
Sodium Fluoride	"	2.81	2.81
Sodium Chloride	"	2.81	2.81
Potassium Fluoride	"	2.69	2.69
Potassium Chloride	"	3.13	3.13
Potassium Iodide	"	3.55	3.55
Magnesium Oxide	"	2.11	2.11

If the shear takes place in such uniform manner that each plane moves over the one beneath it by the same amount, the original arrangement is reproduced and no strain results. If only the alternate planes move, however, the arrangement becomes hexagonal close packing. This is evident from Figs.

14A and 14B, which give the arrangement of atoms in successive close-packed planes (dotted and heavy lines resp.) in the cubic and hexagonal arrangements respectively. In the cubic arrangement there are three different positions of the planes, and these alternate 1, 2, 3, 1, 2, 3, etc. In the hexagonal arrangement there are only two positions, which alternate, 1, 2, 1, 2, etc.

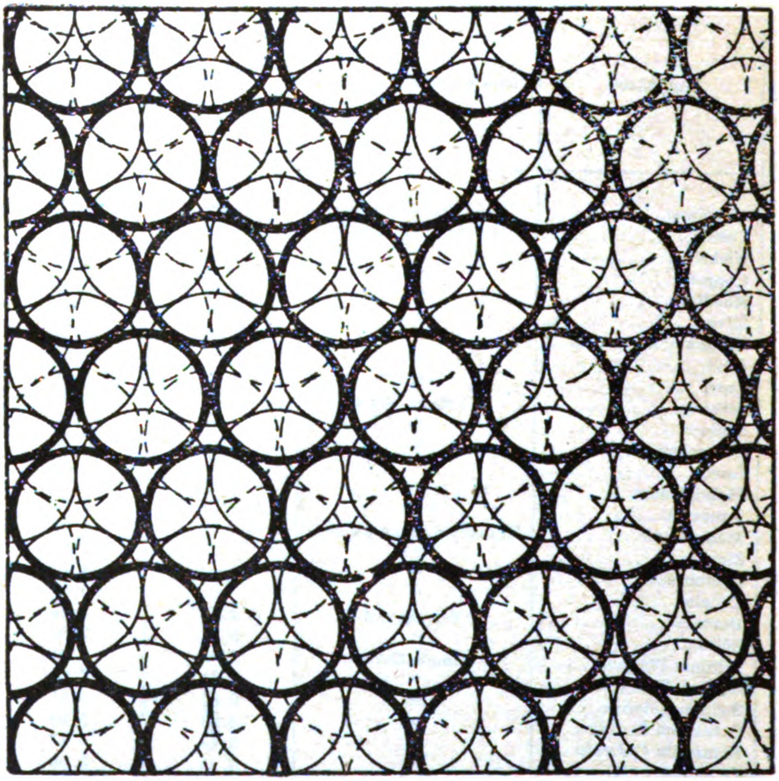

FIG. 14A—ARRANGEMENT OF ATOMS IN SUCCESSIVE PLANES IN CUBIC CLOSE PACKING

In the hexagonal close packed arrangement there is only one set of planes parallel to which this easy gliding can take place. Hence a strained metal becomes less ductile to the extent to which its arrangement becomes hexagonal, and it is evident that mechanical working should produce hardening.

The centered cubic metals should be somewhat less ductile than the face-centered. For the atoms hold on to each other at only 8 points (Fig. 15) instead of 12, and are more likely to move out of each other's influence during gliding.

In the tetrahedral arrangement gliding is impossible. The atoms touch at only 4 points, and in jumping from one stable position to the next would entirely lose hold of each other. This firm interlocking also accounts for the hardness of these substances.

In the case of the simple cubic salts (Fig. 16) gliding is impossible for a different reason. The atoms are held together by electrostatic attraction, each ion being surrounded by six oppositely charged ions. The process of gliding would bring ions of like charge opposite each other, with resulting repulsion and cleavage.

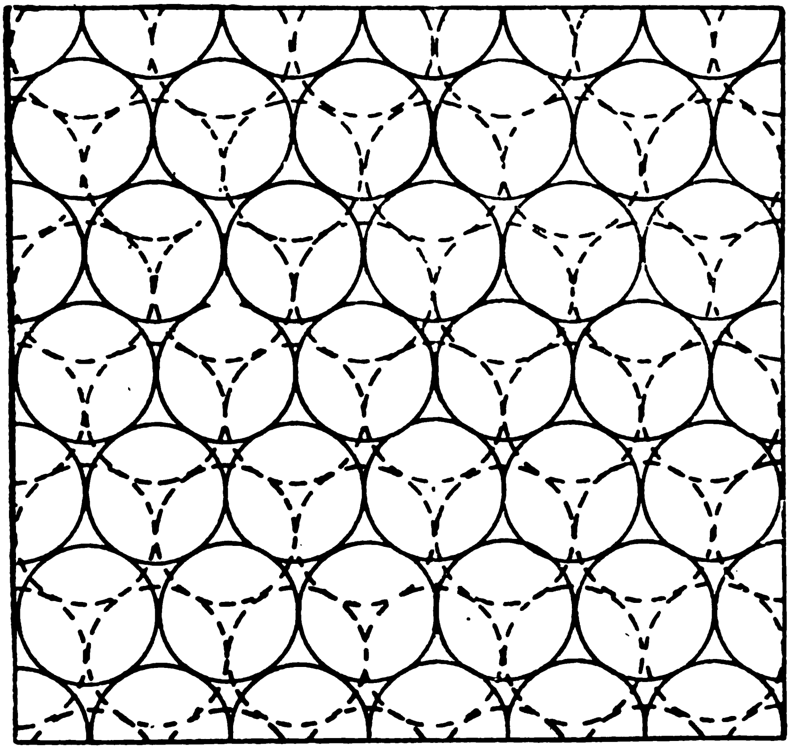

FIG. 14B—ARRANGEMENT OF ATOMS IN SUCCESSIVE PLANES IN HEXAGONAL CLOSE PACKING

The electrical conductivity of metals depends on the ability of electrons to move between the atoms. A discussion of this without a better knowledge of the shape and size of atoms would be premature. It can be seen at once, however, why "ion salts" and crystals like diamond are nonconductors. In each of these arrangements the electrons in the atoms are in complete groups of eight, which is such a stable arrangement[17] that large forces (corresponding to the dielectric strength of the substance) are required to remove them. The atoms of metals, on the other hand, have extra electrons which cannot find places in these stable shells, and are therefore "free" to move from atom to atom.

MAGNETIC PROPERTIES

It is well known that the ferro-magnetism of iron is not a specific property of the iron atom, since iron in solution and in compounds is in general not ferro-magnetic. The ferromagnetism must depend, not only on the nature of the atoms, but on the way in which they are grouped together. It might have been anticipated, therefore, that the cause of ferromagnetism was the *centered cubic arrangement* which is characteristic of iron. A glance at Table I shows that this is not the case. Nickel, which is ferro-magnetic, has a face-centered cubic arrangement, like copper. Cobalt is sometimes like copper, sometimes like magnesium. Neither is like iron. Chromium, on the other hand, which is not ferromagnetic, has a centered cubic arrangement like iron. Manganese has not yet been obtained sufficiently pure to determine its arrangement. It is evident, therefore, that while the centered cubic arrangement may be favorable to ferro-magnetism, and may make iron more magnetic than cobalt and nickel, it is not the principal or even an essential factor.

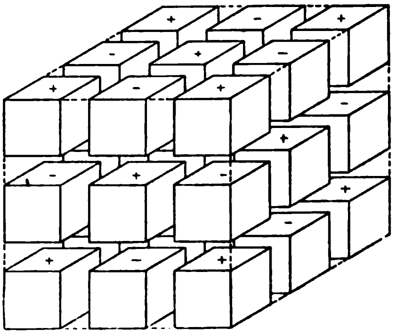

FIG. 16—PACKING OF ATOMS IN SIMPLE CUBIC ARRANGEMENT

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[17] Langmuir, l. c. p. 873.

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(*Subject to final revision for the Transactions.*)

THE VACUUM TUBE AS A GENERATOR OF ALTERNATING-CURRENT POWER

BY JOHN H. MORECROFT AND H. TRAP FRIIS

ABSTRACT OF PAPER

The first part of this article deals with the operation of the tube when separately excited, the variation of power with the amount of excitation, the load impedance, etc., and also gives an analysis of the forms and phases of voltages and currents in the different parts of the circuit.

The second part deals with the efficiency of the tube as a generator; the action is analyzed in detail and the conditions for maximum efficiency deduced, the theoretically deduced conclusions being substantiated by experimental data. Oscillograms are given to show the action of the tube under practically all the conditions which are likely to occur.

THE three-element vacuum tube utilizes the controlling effect of the grid potential on the plate current, that is, the electron flow from the hot filament to the cold (comparatively) plate. It may be used as a detector of high-frequency waves as used in radio communication, or as an amplifier of electrical signals of any frequency or as a generator of alternating-current power of practically any frequency desired, from perhaps one cycle per second to a hundred million cycles per second. This paper deals with its use as a generator; it seems that such a paper is well worth while because of the undoubtedly wide use which will be made of the tube as a convenient source of high-frequency power, especially for laboratory purposes.

A three-electrode tube, such as the Type P pliotron, will give about 500 watts of high-frequency power at any frequency desired. In addition to the tube itself there is required a small continuous current generator of about 2500 volts and a set of suitable coils and condensers. Its only competitor as a piece of necessary laboratory apparatus in the high-frequency alternator; this is however no true competitor, its comparatively high cost, difficulty of speed control, limitation of fre-

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Manuscript of this paper was received September 5, 1919.

quency, decrease of output at frequencies differing widely from that for which it was built, attention required to maintain it against mechanical failure, noise, low efficiency, etc., make the vacuum tube superior unless several kilowatts of power are required. Even then the flexibility of the tube circuit gives it a marked advantage over the machine. For the very high frequencies the tube is the only practical source of power.

Power output of the tube and its variation under different conditions. The relation between plate current, grid potential, and plate potential, is given by the equation

$$I_p = A\,(E_p + \mu_0\,E_g)^x \tag{1}$$

in which E_p = plate potential, referred to filament,
E_g = grid potential,
I_p = plate current,
A = a constant, depending on the size and spacing of the parts of the tube.

The factor, μ_0, is called the theoretical voltage amplification factor of the tube; it really indicates the relatively effectiveness of the grid and plate potentials in controlling the plate current. The exponent, x, has been given as 1.5 and 2 by various writers; it is however a variable, not a constant. Its value is nearly 2 for most tubes throughout a large variation in E_p and E_g, but for extreme values of either, x departs widely from this value. Equation **1** is based on the assumption that the plate current is not large enough to draw from the filament all of the electrons emitted from its hot surface, that is, I_p is less than the saturation current of the tube.

The study of the output, phase relations, etc., was carried out with a type P-10 pliotron, rated at 1000—2000 volts on the plate, filament current of 3.65 amperes, and a safe loss on the plate of 250 watts. The connections were as shown in Fig. 1; in reality the grid is placed between the plate and filament but in this diagram, as in the succeeding ones, we have placed it on the opposite side of the filament to gain clarity in the circuit diagrams. The continuous-current generator E_b furnishes about 1000 volts to the plate through a choke coil L_1, this being suitably large. The continuous-current generator E_c serves to maintain the grid at an average negative potential of any desired amount, and the alternator E_g furnishes the exciting potential to the grid. The condenser C_1 must have a comparatively low reactance; in series with this is the load resistance R, which absorbs the alternating current power generated.

The alternating-current resistance of the plate circuit of the tube R_p is the factor which determines how large L_1 and C_1 must be; the value of R_p varies somewhat with the magnitude of the exciting voltage E_g. For values large of E_g it is equal to E_b divided by I_b, if the resistance of L_1 is low; if this resistance is appreciable the voltage E_p must be used instead of E_b. For small values of the exciting voltage E_g the value of R_p is lower than this, perhaps one half or one third. The values of L_1 and C_1 must be so chosen that for the frequency used the reactance of L_1 is large compared to R_p and that of C_1 is small compared to R_p.

When the grid potential fluctuates the plate current must vary in magnitude according the relation given in equation **1**; this fluctuating current is equivalent to a continuous current with an alternating current superimposed; the alternating component will practically all flow through the R-C_1 circuit because of the high reactance of the coil L_1.

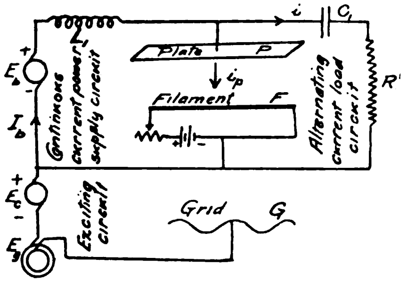

L1
i
C1
+
Eb
-
Ib
Continuous current power supply circuit
Plate P
ip
Filament F
+
-
Alternating current load circuit
R'
+
Ec
-
Eg
Exciting circuit
Grid G

FIG. 1

The first effect studied was the variation of output as the value of the load resistance R, was varied, the excitation being comparatively low; the results are shown in Fig. 2. The curve sheet shows the variation of the various quantities as the value of R was changed; it is seen that a maximum output occurred with R equal to 1000 ohms. For the conditions of this test the value of R_p was 1100 ohms, although the quotient of E_p and I_b gives very nearly 3000 ohms.

In Fig. 3 is shown the behavior of the circuit as the exciting voltage, E_g was varied; the connections were the same as those of Fig. 1. The alternating-current output increases with the square of the exciting voltage up to a certain value of E_g and then increases more slowly. For the lower values of E_g (less than 120 volts) the fluctuating plate current has an approximately sinusoidal form but for the higher values the plate current becomes a series of pulses.

The decrease in I_b in Fig. 2 and increase in Fig. 3 are both due to the fact that the relation between grid potential and plate current is not linear; if sufficient resistance is put in the load circuit I_b remains nearly constant as the value of E_g is changed.

In Fig. 3 is shown the grid current, as read on a continuous current ammeter; this reached a readable value when the effective value of E_g reached 95 volts. The maximum value of E_g is 134 volts and as E_c was 120 volts it is evident that the grid had to be positive as much as 14 volts before it took an appreciable current. The value of E_g at which I_g becomes readable depends to some extent on the value of the load resistance R.

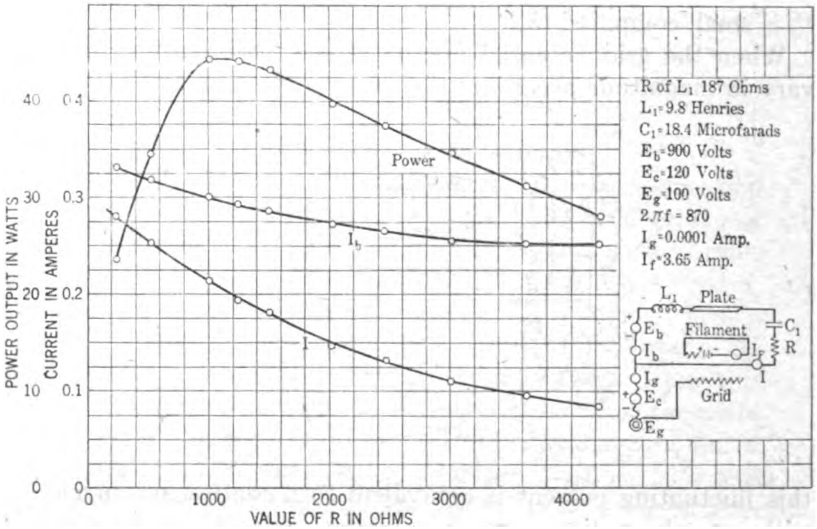


FIG. 2

Safe load of a vacuum tube. The two factors limiting the output of a vacuum tube are the safe filament current and the amount of power which can safely be dissipated from the plate (generally double). The heating of the plate is due to the bombardment by the electrons leaving the filament, being accelerated by the high positive potential of the plate, and then being suddenly stopped when impinging on the plate. With a properly evacuated tube the amount of power which can be thus expended on the plate is sufficient to bring it to a dull red heat, this color being judged when the filament is incandescent; if the filament current is quickly reduced to zero the plate has quite a bright cherry red color.

When the tube is not generating any alternating current power all of the input $E_b I_b$ is used in heating the plate but when alternating current is flowing in the load circuit some of the power supplied to the tube circuit is used up in R and the amount of power used on the plate is equal to $E_b I_b$ minus

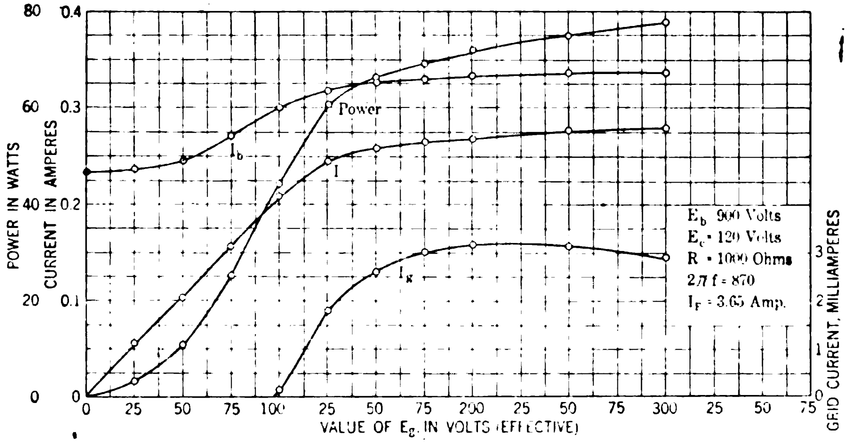


FIG. 3

whatever power is used in the R-C_1 circuit. If the values of E_c and E_g are properly adjusted the amount of power used in R may be equal to or even greater than that used on the plate so the safe value of $E_b I_b$ may be as much as three times the safe plate rating without endangering the tube; if however the tube stops oscillating for any reason the input must be at once reduced or the tube will probably be spoiled.

An approximate idea of the behavior of the tube circuit as the exciting voltage is increased is given in Fig. 4; assuming a constant input the output and losses follow the variation shown. The efficiency may reach quite high values when suitable adjustments are made. In the small sets used by the Signal

Corps the tubes were adjusted for an efficiency of about 30 per cent but it has been found possible to so adjust one of these tubes in the laboratory as to get a fair output with an efficiency better than 70 per cent.

Phases and Forms of Currents and Voltages in a Tube Circuit. If the impedance of the power supply circuit (Fig. 1) is very high compared to that of the load circuit the current I_b is constant, and the equations of the alternating current circuit may be worked out as though the power supply circuit did not exist.

When a voltage $E_{mg} \sin \omega t$ is impressed on the grid the changes produced in the plate current are the same as though a voltage $\mu_0 E_{mg} \sin \omega t$ had been introduced into the plate circuit. The changes produced in the plate current circuit by the grid excitation may be calculated on the assumption that the voltage $\mu_0 E_{mg} \sin \omega t$ was operating in the plate circuit. Thus a voltage E_g on the grid is replaced in our calculations by a suppositious voltage $\mu_0 E_g$ in the plate circuit; the current produced by this voltage can be at once calculated from the impedance of the circuit in which the alternating current must flow, namely R_p, R, and C_1 in series.

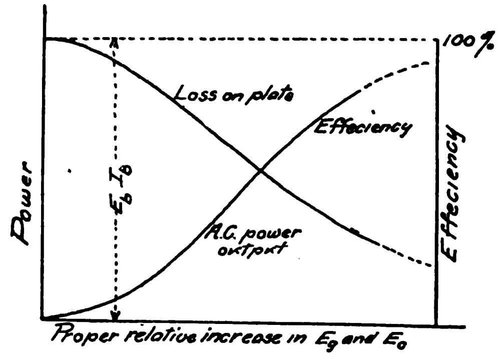


FIG. 4

The vibrators of an oscillograph were introduced in the circuit as shown by Fig. 5 and the polarities so adjusted that currents in the directions indicated by the arrows are positive; when a current is shown on its film below the zero line the direction of the current was in the opposite direction to that shown by the arrow. The oscillograph used had only three vibrators; it was sometimes necessary to take several exposures to get all the quantities wanted. This was done by always running the film at the same speed and making one curve (generally i_p) common to all films; it was then possible to so place the films together for reproduction that all quantities were in their correct relative phases.

In the first circuit tested the total resistance in the alternating-current circuit (R_p plus R) was about 4000 ohms and the reactance of the condenser C_1 was 62 ohms; we should expect therefore that the current I_p and voltage E_g would be in phase and moreover if the grid excitation is kept low the alternating component of the plate current, I_p, should be of the same form as the grid voltage. Then as the voltage e_p is determined by the constant voltage E_b and the drop in R, this voltage must also have a sine wave fluctuation in such phase that when the plate current is a maximum the plate voltage is a minimum. Fig. 6 shows the form of plate voltage, plate current, and grid voltage, for the conditions noted below the film. It will be seen that both e_p and i_p are sinusoidal in form and that e_p is 180 degrees out of phase with e_g. The grid current was zero for the conditions given; it may be seen from the film that E_g was not sufficiently large to force the grid to a positive potential.

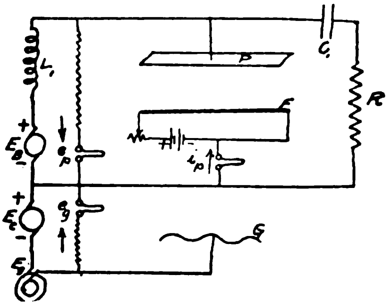


FIG. 5

In Fig. 7 are shown the various quantities for a much greater excitation than was used for Fig. 6. The plate current rises to a value of 0.66 amperes and decreases to zero; the current flowing in the alternating current circuit must therefore have a maximum value of 0.33 amperes giving an $I\,R$ drop in R equal 330 volts. The fluctuation in e_p as measured in the film is 340 volts. The grid takes current all the time the grid is at positive potential, but it is very small, due to the fact that the plate potential never falls to lower than 660 volts.

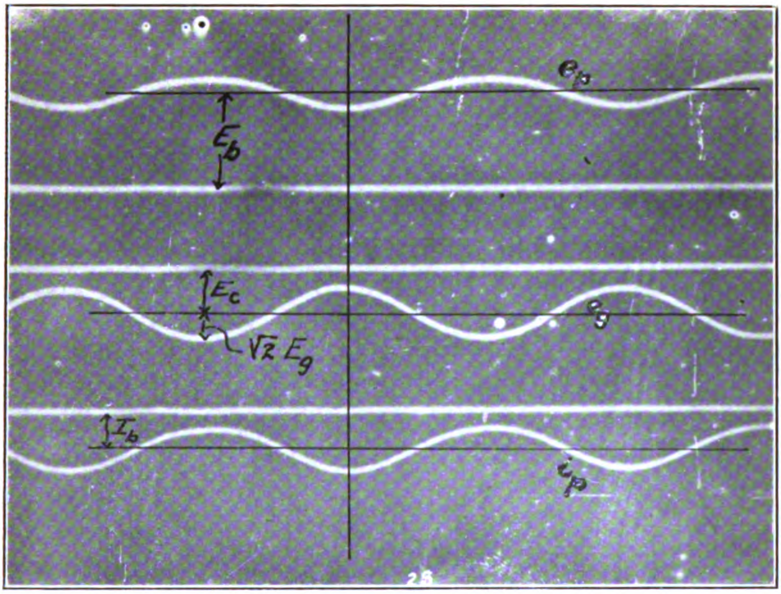
If a greater variation in the plate voltage is desired it can be brought about only by increasing the value of R; if this had been 3000 ohms instead of 1000, the plate potential would have fluctuated from zero to 2000 volts. As the normal maximum output is obtained from a tube when both i_p and e_p vary from zero to twice their normal values it is evident that R should have been increased to 3000 ohms to get maximum output. But by referring to Fig. 2 it would seem that 1000 ohms was the proper value of R for maximum output. This discrepancy arises from the fact that the results for Fig. 2 were obtained with low grid excitation while the curves in Fig. 7 were obtained with an excitation three times as large. As previously stated, R_p varies with the excitation, and the maximum output is obtained when the load resistance and tube resistance are the same.

The amount of fluctuation in I_b is small; the value of the alternating component is fixed by the requirement that the reactance drop in L_1, due to it, must be equal to the alternating component of the fluctuating plate voltage. If the fluctuation in e_p were sinusoidal the fluctuation in I_b would also be of that form.

With lower values of load resistance the distortion in plate current occurs even with low excitation; this is shown in Fig. 8 for which R had a value of only 100 ohms. Although there was the same alternating current produced in the output circuit as for the case given in Fig. 7 the fluctuation in plate voltage is very small, due to the very low impedance of the load circuit.

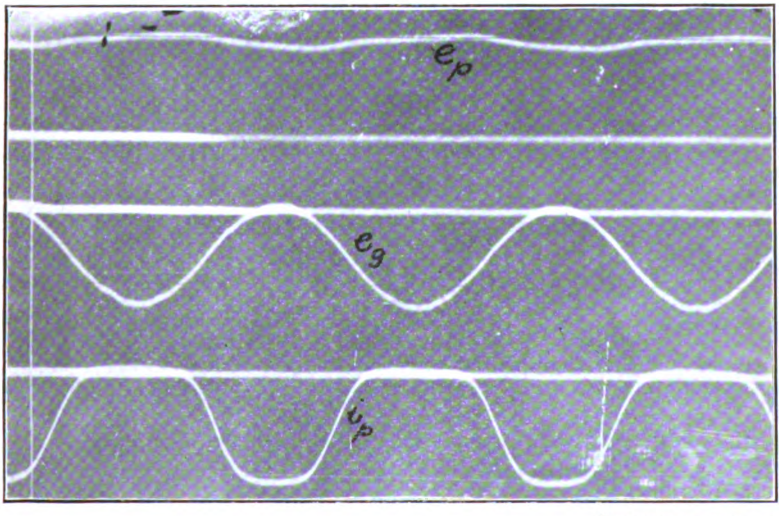
The alternating current of the tube circuit may be analyzed by the laws of the ordinary circuit, in case we are interested only in the sine wave components of the quantities studied. The vector diagrams of the three possible kinds of load circuits are shown in Fig. 9; in these diagrams cos ϕ gives the power factor of the load circuit itself and cos θ gives the power factor of the whole alternating current circuit, including the resistance of the tube as well as the load circuit resistance.

In Fig. 10 are shown the curves of e_p, e_g, and i_p for circuits corresponding to those assumed in Fig. 9; the three circuits as actually used had the same excitation and nearly the same magnitude of impedance in the load circuit, the first being resistive, the second, capacitive and the third, inductive. With resistive load the plate current (alternating component) is in phase with the voltage E_g, with the capacitive load it leads and with the inductive load it lags; the angles ϕ and θ



$E_b = 900$ $I_b = 0.25$ $E_c = 120$ $E_g = 50$ FREQUENCY = 140
LOAD $R = 1000$ OHMS $C = 18.4\ \mu f$

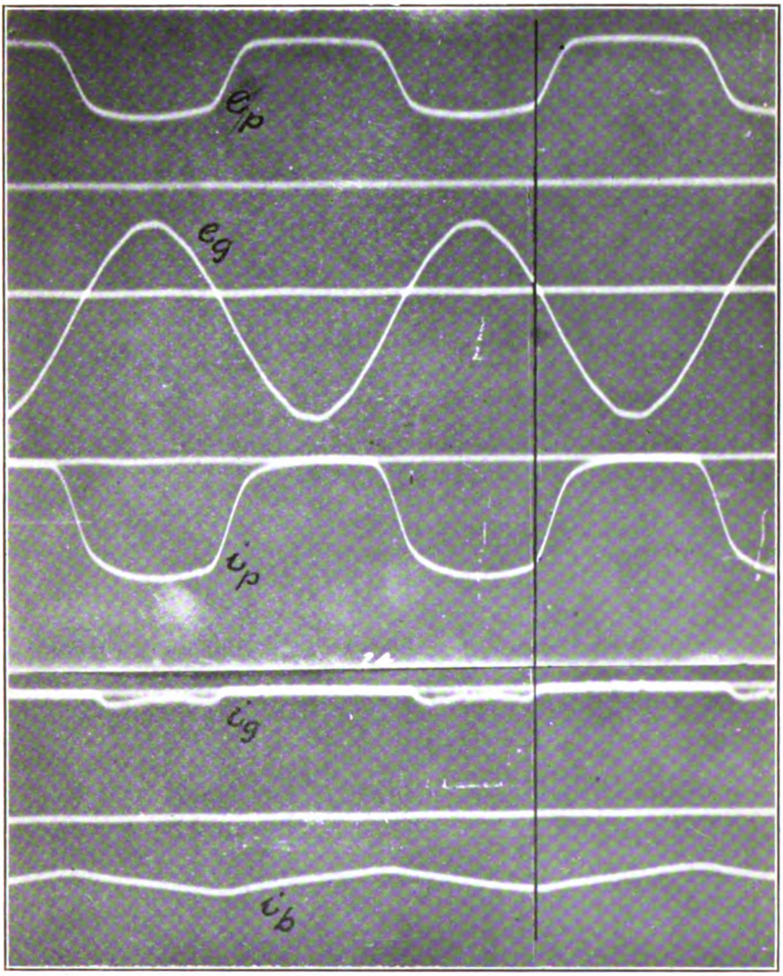
FIG. 6



[MORECROFT & FRIIS]

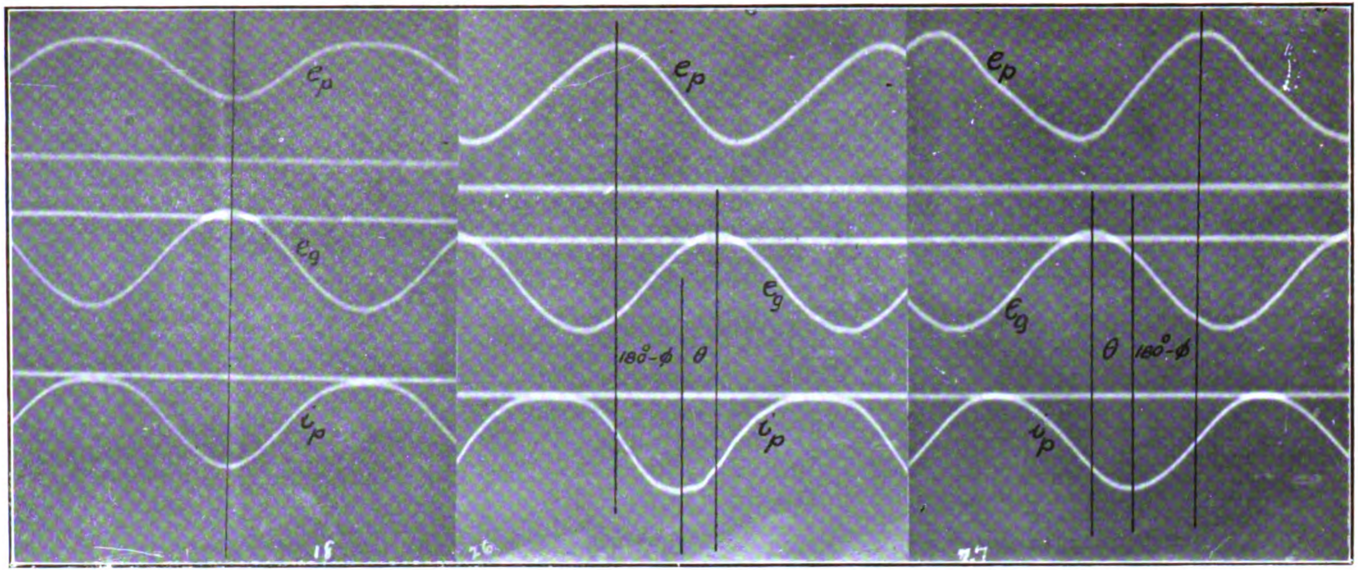
$E_b = 900$ $I_b = 0.34$ $E_c = 120$ $E_g = 100$ $f = 140$
LOAD $R = 100$ OHMS $C = 18.4\ \mu f$

FIG. 8



[MORECROFT & FRIIS]

$E_b = 900$ $I_b = 0.34$ $E_c = 120$ $E_g = 300$ $f = 140$
LOAD $R = 1000$ OHMS $C = 18.4\ \mu f$
FIG. 7



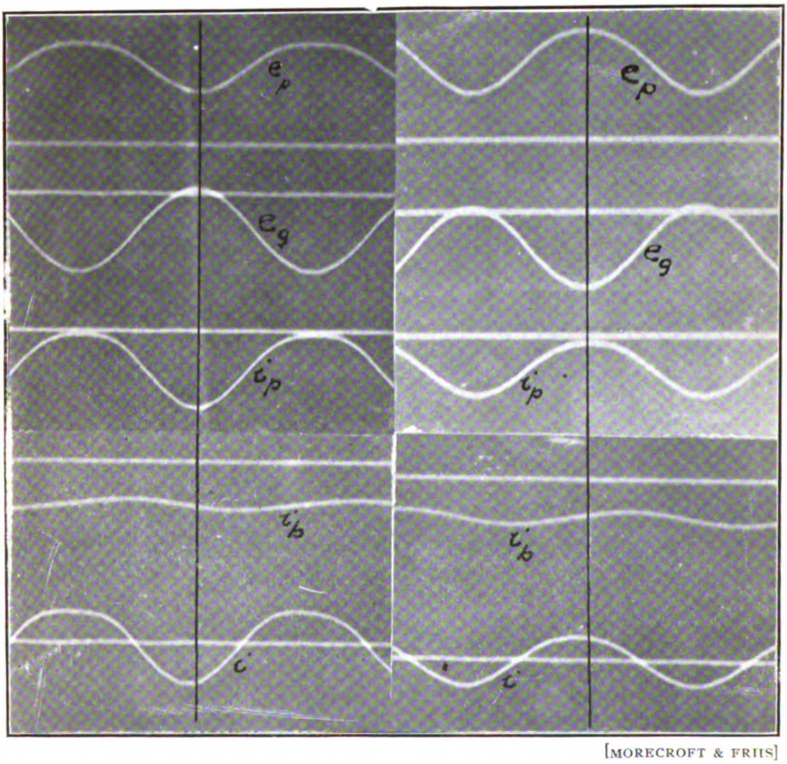
[MORECROFT & FRIIS]

RESISTANCE LOAD
$R = 1000$ OHMS

CAPACITIVE LOAD
$R = O \quad \frac{1}{\omega C} = 1350$ OHMS

INDUCTIVE LOAD
$R = 30$ OHMS $\quad \omega L = 1500$ OHMS

FIG. 10



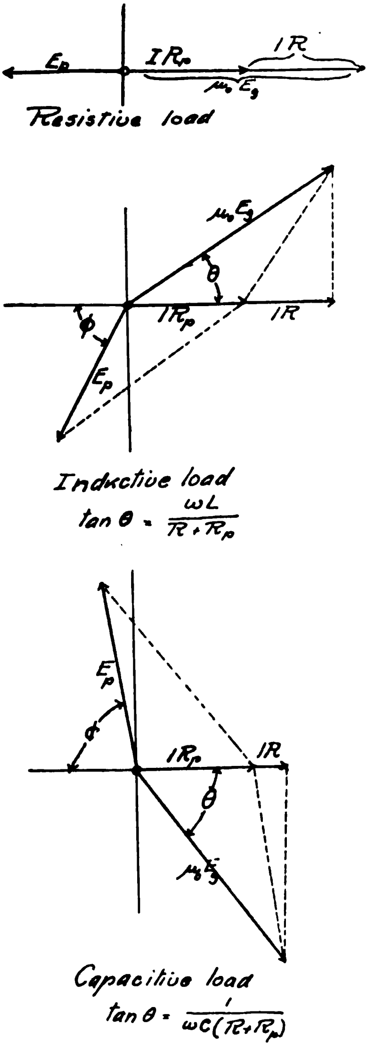
[MORECROFT & FRIIS]

$E_b = 900$ $E_c = 120$ $E_g = 100$ $f = 140$

$I_b = 0.295$ $R = 1000$ $I_b = 0.272$ $R = 2010$

FIG. 11

measured from the film, and the calculated values, agree within the precision of measurement.



Phase relations in tube circuits

FIG. 9

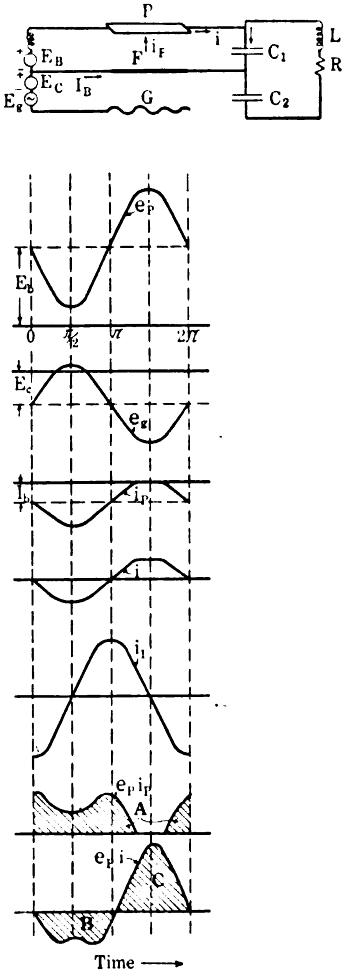


FIG. 13

There is considerable distortion in all three circuits which could have been nearly eliminated by increasing the impedance of the load circuit to about three times the value used. This would however, have required a corresponding increase in the inductance of L_1 and a suitable coil was not at hand.

The effect of varying the resistance of the output circuit is well shown in Fig. 11; in one case the resistance was 1000 ohms and in the other it was 2000 ohms. It will be seen at once that the distortions produced by the tube can be reduced by sufficiently increasing the impedance of the output circuit. In the case given in Fig. 11 the reactance of the power supply circuit was not increased when the resistance of the output circuit was increased with the result that a much larger fraction of the generated alternating current passed through the supply circuit in the second case than in the first. The greater the amount of alternating current power used in the power supply circuit, of course, the less efficient is the circuit.

EFFICIENCY OF A TUBE

From the oscillograms given thus far it would appear that the efficiency of a tube generator could not be very high. On the assumption that the plate current and plate voltage both have sinusoidal variations the maximum possible output of the tube would be just half the input; such a high fraction could not be obtained however because the conditions required could not be satisfied. The plate voltage would have to fluctuate between $2\,E_b$ and zero and the plate current between $2\,I_b$ and zero; this latter condition could be satisfied but the first could not be. The plate voltage must not fall below a certain minimum if high efficiency is to be obtained because of the excessive grid current resulting. With the tube we used this minimum was about two hundred volts.

The possible efficiency of 50 per cent mentioned above, it must be remembered, does not consider the amount of power required for heating the filament nor the possible losses in the exciting circuit. If these losses are considered the possible efficiency would be much less, especially in the smaller tubes. We shall now show however that by using peculiar shaped plate currents it is possible to have an efficiency considerably in excess of 50 per cent; in fact the result of this study is that the efficiency of a tube may be pushed possibly as high as 90 per cent by proper design and proper operation, this value neglecting the filament power input.

The importance of getting a high efficiency will be at once appreciated when it is mentioned that a given tube (the one used in this test) has an output of about 200 watts in normal operation whereas if the efficiency could be increased to 90 per cent the safe output would be 2250 watts.

The tests carried out involved an adjustment with separate excitation to find the conditions for maximum output and then transferring the grid connection to a proper point of the circuit to get self excitation, recording for each condition the forms and phases of currents and e. m. fs. The tests were run at low frequency so that oscillograph records might be obtained; the results obtained were duplicated later in a high-frequency run.

Fig. 12 shows the circuit used; simpler ones may be used but the laboratory apparatus at hand was best suited to this one. The diagram also shows where the oscillograph vibrators were introduced and the direction of currents assumed as positive; if, on a film, a current is shown below its zero line, it was flowing in the opposite direction to that shown in the diagram. If the frequency of the exciting voltage E_g is chosen the same as the resonant frequency of the load circuit

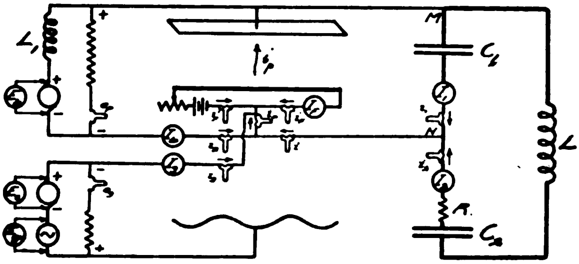


FIG. 12

$$\left(f = \frac{1}{2\pi \sqrt{L\left(\frac{C_1 C_2}{C_1 + C_2}\right)}} \right)$$

the impedance of this circuit between the two points M and N, where the tube is attached, will be resistive only, its magnitude being equal to $\frac{1}{\omega^2 C_1^2 R}$ ohms.

The quantities to be considered are shown conventionally in their phases in Fig. 13; the current i_1 which flows in the resonant load circuit may be several times as large as the current i, furnished by the tube. The two important things in this diagram are shown in the lower part of the figure, namely, the curves of $e_p\, i_p$ and of $e_p\, i$. These curves give the power loss on the plate and the power supplied by the tube to the load circuit, respectively. It is at once evident that

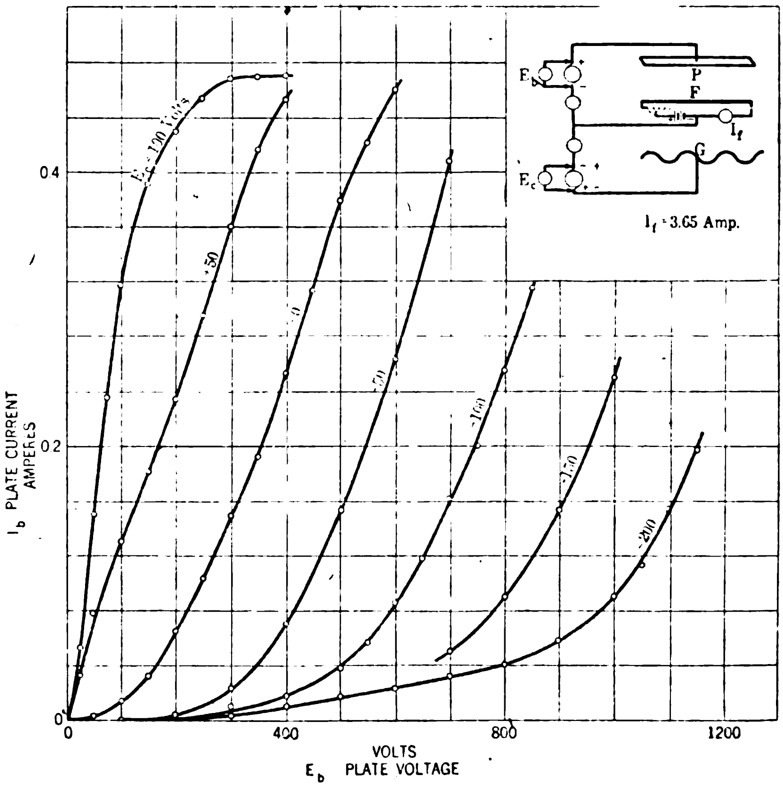


Fig. 14

$$\text{Energy loss on plate per cycle} = \int_0^{2\pi} e_p\, i_p\, dt = \text{Area } A$$

$$\text{Energy supplied to load circuit} = \int_0^{2\pi} e_p\, i\, dt = \text{Area C} - \text{Area } B$$

It is evidently desirable to make the latter as large as possible and the former as small as possible, if the tube circuit is to operate efficiently. Any ordinary scheme of analysis, using the relation given in equation 1 must fail because the relation does not hold good for those values of e_p and e_g which are the most important ones in the cycle of operation, namely low e_p with positive e_g, and very high values of e_p with large negative e_g.

The ordinary so called static characteristics of the tube used are given in Fig. 14; they are not of much service in predicting the behavior of the tube when the output is forced as high as possible. They did bring out the fact however that the filament ammeter if a continuous current instrument does not read correctly the filament current when the tube is generating alternating current power. The ammeter indicated 3.65 amperes when getting the curves of Fig. 14 and the total emission for such a current is evidently about 0.5 amperes. Now when the tube was oscillating, the filament ammeter reading 3.65 amperes the total emission was about 0.8 amperes, showing that the filament temperature was much hotter than when not oscillating. Holding the voltage across the filament constant (approximately the condition when the tube is oscillating) the set of curves given in Fig. 15 were obtained. The grid was held at a positive potential of 100 volts and the plate

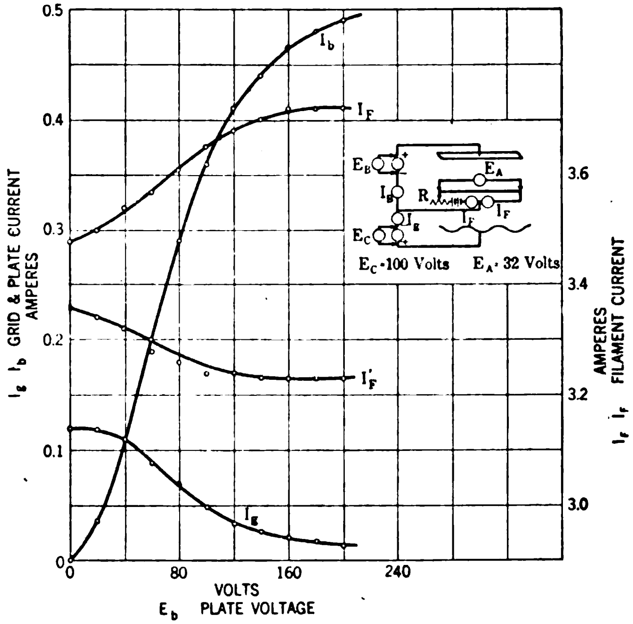


Fig. 15

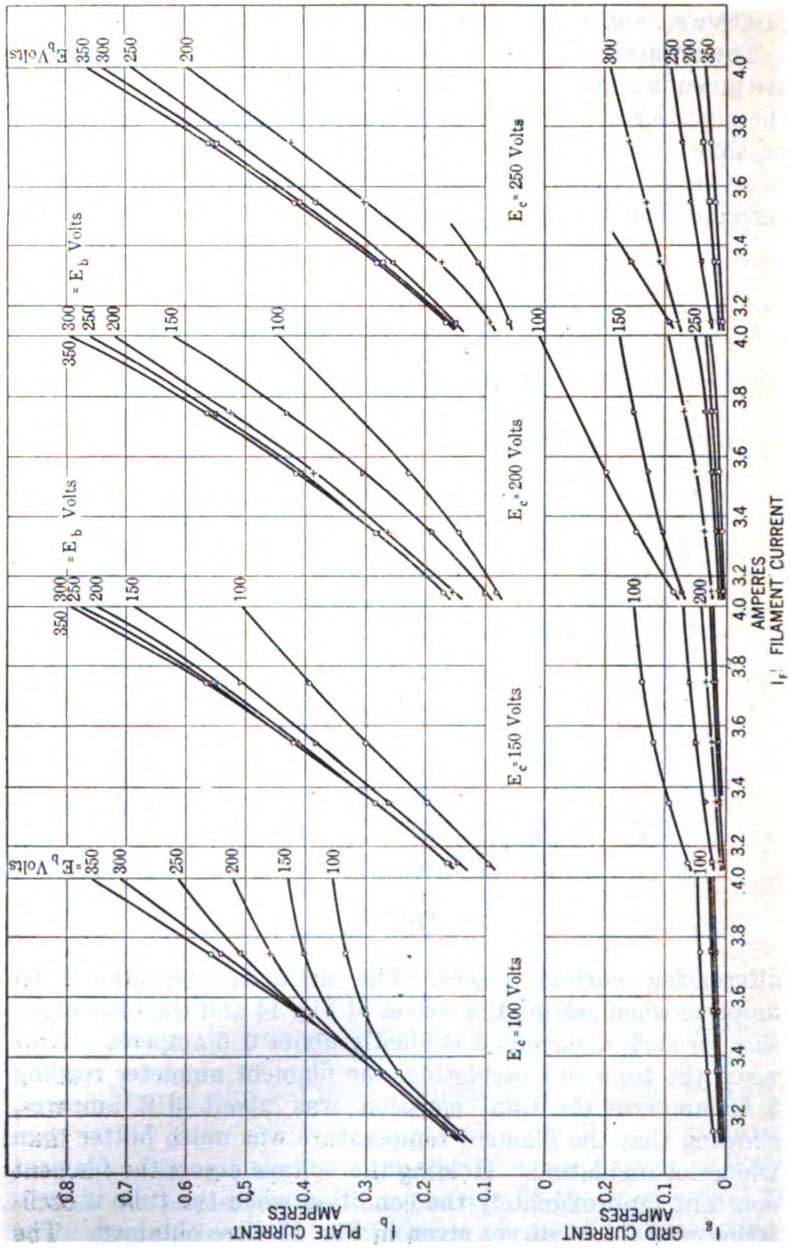

I_b PLATE CURRENT AMPERES
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
I_g GRID CURRENT AMPERES
0.2
0.1
0
E_c = 100 Volts
E_c = 150 Volts
E_c = 200 Volts
E_c = 250 Volts
E_b Volts
= E_b Volts
350
300
250
200
150
100
3.2
3.4
3.6
3.8
4.0
I_f FILAMENT CURRENT AMPERES

Fig. 16

voltage suitably varied. The electron current to the plate increases the filament current at one end and decreases it at the other; the relative increase and decrease will be determined largely by the resistance used in series with the filament battery. It can be seen that even with the larger filament current as great as 3.75 amperes the emission was only 0.5 ampere.

From some preliminary oscillograph records we knew that in operation the total emission was about 0.8 ampere when the filament ammeter read 3.65 amperes. A brief test showed that the filament current required to give this much emission

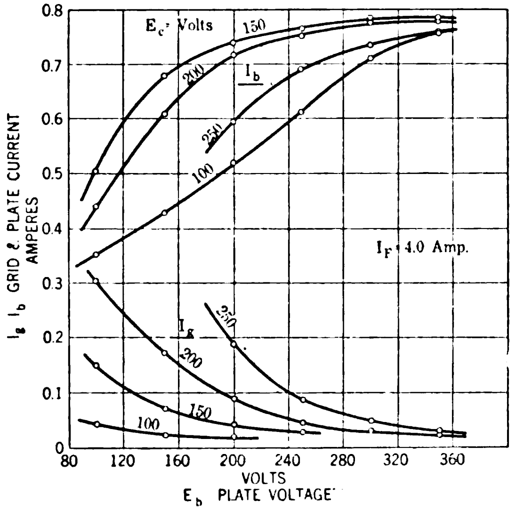


Fig. 17

was 4.00 amperes but this seemed like an excessive current so we got the characteristics required from extrapolation. In Fig. 16 are shown a set of curves showing the variation of plate and grid currents for various filament currents and grid and plate potentials. From this set of curves the results given in Fig. 17 was obtained; as these are important curves they were verified for correctness of form by actually getting them for a lower filament current. These are given in Fig. 18, and are of just the same form as those of Fig. 17.

It is well to point out here that even if we had been able to get the curves of Fig. 17 with a filament current of 4.00 amperes they would not have given the proper values of i_p and i_g for the tube in operation. While getting these static characteristics the plate and grid get very hot, much hotter than when the tube is in operation as a generator. The emission from the filament is fixed by the filament temperature, and this in turn is fixed by the filament current and the temperature of the plate; if this is hotter when getting the static characteristics than when the tube is generating, the value of i_p and i_g obtained would probably be too large.

The curves of Fig. 17, in connection with Fig. 13 enable us at once to give the minimum potential to which the plate should drop and the maximum positive potential for the grid. In order to make the area *A* Fig. 13 small the plate potential, at time $\pi/2$, should be as low as possible. This minimum will be controlled however by the other requirement that the area *C* should be large. If during the time when e_p is low i_p does not have its maximum possible value (saturation current) then the positive alteration of *i* will not be as large as it should be and if this is not large the power input to the load circuit, determined principally by the area of *C*, will be lower than its proper value.

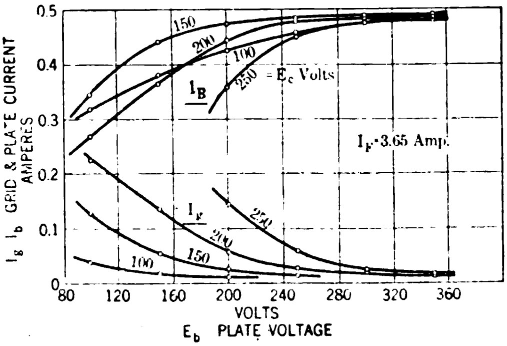
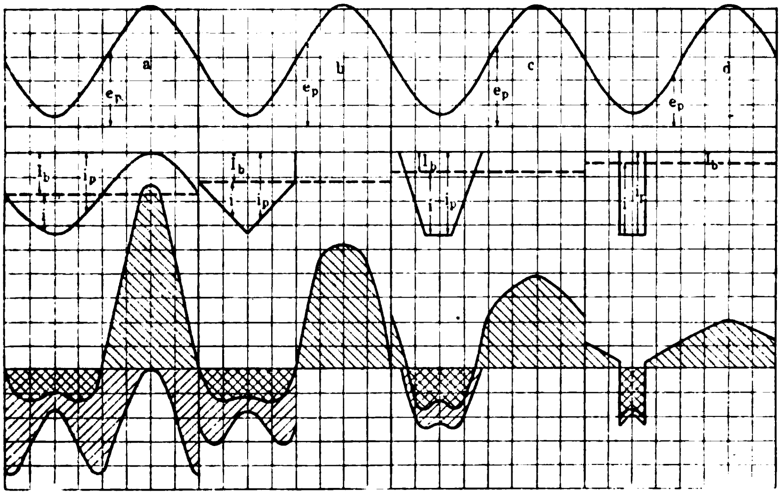


FIG. 18

As the average value of *i* must be zero, if its positive loop is to be as large as possible, and the area of *A* to be kept as small as possible the conditions should evidently be so adjusted that at minimum plate potential saturation current should flow, and this flow should last for a short time only. During the rest of the cycle the plate current should be zero.

Fig. 19 shows the calculated losses on the plate and input to the load circuit for four different forms of plate current, the plate voltage having the same form for each. It will be seen that both the losses and the output of the tube are greatest for the sinusoidal plate current, but the efficiency for this condition is only 39 per cent; as the form of plate current approaches a short pulse the efficiency increases, being 82 per cent for the form shown in curve (*d*). The trapezoidal form shown at (*c*) resembles very closely the form we used; the test actually gave about 60 per cent efficiency.

All four curves are drawn with the maximum plate current the same, supposedly the saturation current for the filament current used; by carrying out other constructions it will be evident that any other condition would result in poorer operation.

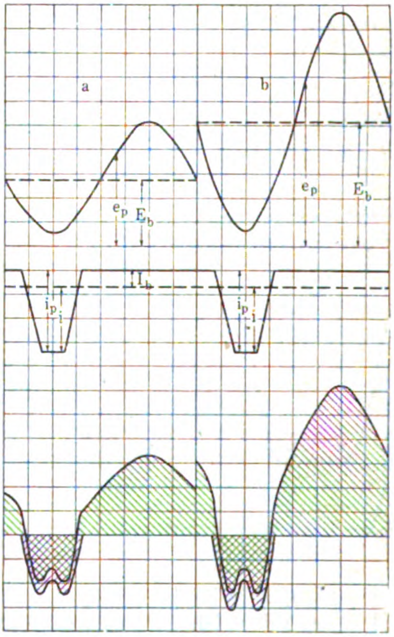


$\int e_p i_p dt = 72$	$\int e_p i_p dt = 35$	$\int e_p i_p dt = 20$	$\int e_p i_p dt = 7$
$\int e_p i\, dt = 47$	$\int e_p i\, dt = 31$	$\int e_p i\, dt = 28$	$\int e_p i\, dt = 33$
EFFICIENCY = 39%	EFFICIENCY = 47%	EFFICIENCY = 59%	EFFICIENCY = 82%

FIG. 19

By referring to Figs. 13 and 17 it may be seen that for the tube we had the plate potential should not fall lower than 200 volts, that at this time the grid should have a positive potential of 150 volts. With greater or less grid potential, the plate potential being 200 volts, the plate current would be less than saturation value; with less plate potential the current (at time $\pi/2$) would be less than saturation value, and with greater voltage than 200 volts the loss on the plate would be greater than necessary.

It is to be noted that the efficiency will increase for all the cases given in Fig. 19 if the value of the power supply, E_b, is increased, providing that conditions are suitably changed to have the same minimum plate voltage as given in Fig. 19. This is shown by Fig. 20; the two cases given suppose the same form of plate current and same minimum value of plate voltage but in the second the voltage E_b is about twice as large as in the first case. It is seen that the loss on the plate is increased only 25 per cent whereas the input to the load circuit has been more than doubled. The higher the value of E_b the higher is the efficiency, the limit being fixed by the safe voltage for the tube.



$\int_0 e_p i_p \, dt = 15$
$\int e_p i \, dt = 34.5$
EFFICIENCY = 70%

$\int e_p i_p \, dt = 19$
$\int e_p i \, dt = 71.5$
EFFICIENCY = 79%

FIG. 20

In the tube we used the efficiency did not rise as high as might be expected, due to fact that it took excessively high negative potential on the grid to bring the plate current to zero. The oscillograms showed this effect so a static characteristic curve was taken to investigate this point; it is shown in Fig. 21. If equation 1 were valid for this tube a negative potential of 260 volts on the grid would have brought the plate current to zero, whereas it took about 1000 volts; although the plate current is small with a grid negative more than 300 volts this small current has a marked effect on the loss of power on the plate, because of the very high plate voltage during that part of the cycle when this small current is flowing to the plate.

Experimental proof of foregoing theory. To test the validity of the ideas presented above a series of runs was made with the tube, using the circuit given in Fig. 12 and the results therefrom are shown in Table I. The frequency was kept at the resonant value for the output circuit and each time a set of readings was taken the value of R was changed properly to maintain the current in the oscillating circuit constant. This was necessary in order to keep the form of the voltage, e_p, constant as the values of E_c and E_g were varied. While it was not thus pointed out in discussing the current forms of Fig. 19 and 20 the values of E_c and E_g are the factors which bring about the change of current form as the form of e_p is maintained constant. The form of current shown in (a) Fig. 19 was obtained with relatively low E_c and E_g, the value of each of these being increased for the succeeding diagrams of the figure.

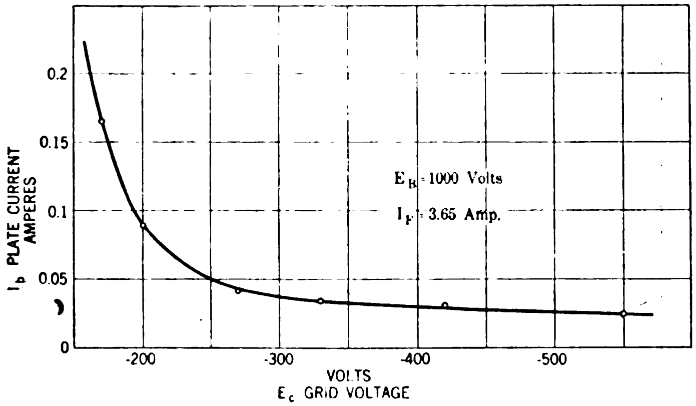


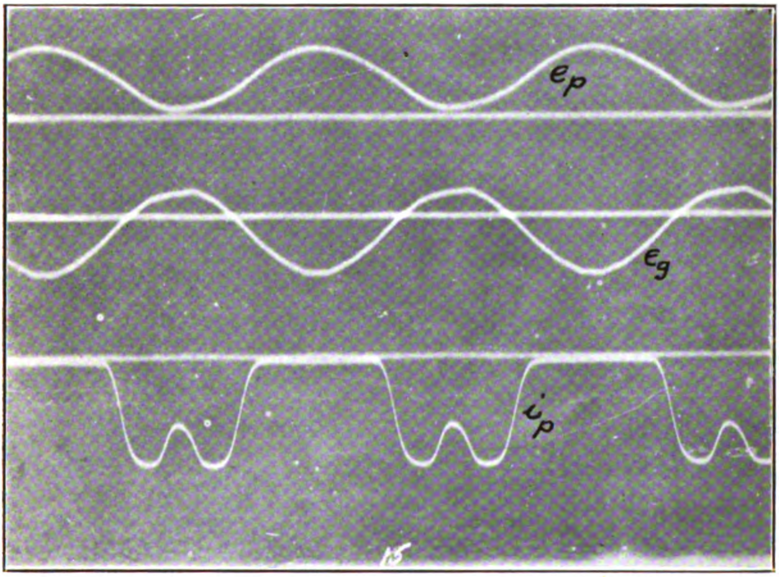
FIG. 21

In Fig. 22 are shown the efficiency curves for the various runs of Table I and on the curve sheet are given the calculated values of the maximum positive grid potential for that condition in each run which gave maximum efficiency, as indicated at *a*, *b*, *c*, *d*, etc., For the comparatively low value of current in the oscillating circuit which obtained during these tests the form of plate voltage is somewhat different from a sine wave, and the variation of best grid potential may have been due to this cause. The increase in efficiency with increase of E_g

TABLE I.

E_b = 1000 volts. $C_1 = 2 \mu F$. $C_2 = 3.91 \mu F$. $\sim = 138$. $L_1 = 9.8H$. $I_f = 3.5$ Amp.

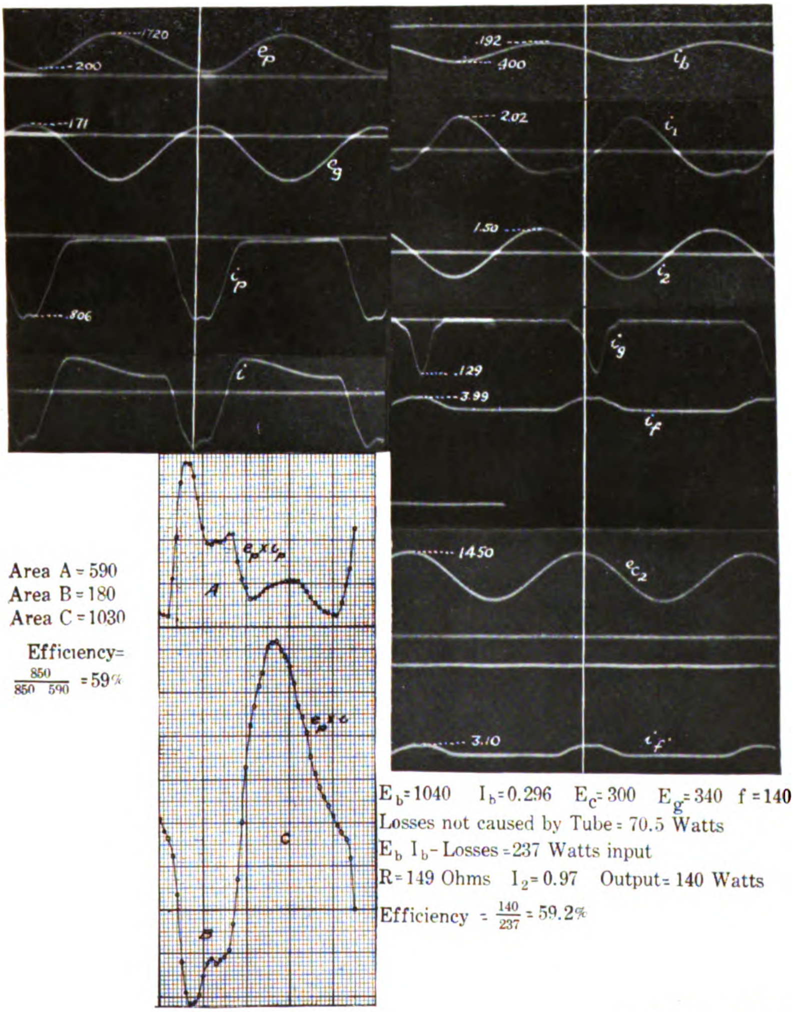
Run	E_c volts	E_g effective volts	Input watts	I_2 effective amps.	R ω	Output RI_2^2 watts	$\eta = \frac{\text{Output}}{\text{Input}}$ %
	120	220	334	0.98	149	143	42.8
	150	220	298	1.00	149	149	50.0
	180	220	241	1.02	119	124	51.5
	210	220	186	1.00	89	89	47.8
	250	220	119	0.96	42	39	32.8
	150	260	302	1.00	149	149	49.3
	180	260	273	1.03	149	158	58.0
	210	260	241	1.99	149	146	60.5
	240	260	197	0.99	119	117	59.5
	270	260	161	0.96	89	82	51.0
	150	300	302	1.00	149	149	49.3
	180	300	283	1.02	149	155	54.8
	210	300	261	1.02	149	155	60.0
	240	300	246	1.00	149	149	60.8
	270	300	212	0.98	134	129	60.8
A	180	340	291	1.01	149	152	52.3
	210	340	278	1.03	149	158	56.8
	240	340	265	1.04	149	161	60.8
	270	340	244	1.01	149	152	62.4
B	300	340	229	0.99	149	146	63.8
	330	340	186	0.99	119	117	63.0
	270	400	260	1.02	149	155	59.7
	300	400	250	1.03	149	158	66.3
	330	400	235	1.02	149	155	66.0
	360	400	222	1.00	149	149	67.3
	390	400	197	0.96	134	124	66.0
	420	400	150	1.02	89	93	61.8
C	450	400	126	0.98	74	71	56.3
D	410	460	228	1.02	149	155	68
	420	500	245	1.05	149	164	67.0
	450	500	237	1.04	149	161	68.0
	480	500	222	1.01	149	152	68.6
	510	500	195	1.04	119	129	66.2
	540	500	176	1.02	104	108	61.5
	570	500	157	1.04	89	96	61.2



[Morecroft & Friis]

$E_b = 1000$ $I_b = 0.348$ $E_c = 180$ $E_g = 340$ $f = 140$
$I_g = 0.038$ Output = 150 watts Efficiency = 54 per cent

Fig. 24



Area A = 590
Area B = 180
Area C = 1030

Efficiency = $\frac{850}{850 \quad 590}$ = 59%

E_b = 1040 I_b = 0.296 E_c = 300 E_g = 340 f = 140
Losses not caused by Tube = 70.5 Watts
$E_b\, I_b$ - Losses = 237 Watts input
R = 149 Ohms I_2 = 0.97 Output = 140 Watts
Efficiency = $\frac{140}{237}$ = 59.2%

[MORECROFT & FRIIS]

FIG. 25

and E_c is as would be expected from the analysis given for Fig. 19.

A run was then carried out (results given in Table II) to study the effect of varying the value of the minimum plate voltage, other conditions remaining the same; this was accomplished by varying R, thus cutting down the value of the oscillating current and hence the variation of voltage across the condenser C_1, Fig. 12. The variation of potential across this condenser, it will be noticed, is what controls the fluctuation of plate voltage.

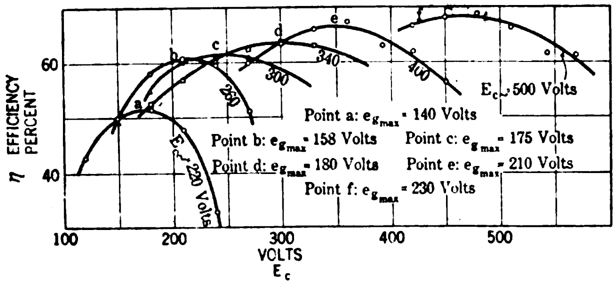


Fig. 22

The value of minimum plate voltage can be calculated by

TABLE II.

E_b = 1000 volts. C_1 = $2 \mu F$. C_2 = $3.91 \mu F$. ~ = 138. L_1 = $9.8 H$. I_f = 3.65 Amp.

e_p min volts	E_c volts	E_g effective volts	Input watts	I_2 effective amps.	R ω	Output $= RI_2^2$ watts	$\eta = \frac{\text{Output}}{\text{Input}}$ watts
30	270	300	134	1.12	37	46.5	34.7
100	270	300	179	1.10	85	103	57.5
160	270	300	204	1.02	117	122	59.8
250	270	300	217	0.91′	149	123	56.8
490	270	300	255	0.60	297	107	42.0

subtracting from E_b the I_b resistance drop through L_1 (which was very small for most of our tests) and from this subtracting, the maximum value of the alternating potential drop across C_1. These calculations were made and the results are shown in the curve of Fig. 23; the results verify, better than might be expected, the conclusions reached from theory. Too much reliance cannot be placed on the results of this test however as the exact form of the e_p curve might affect the results considerably and the form of this curve was not ascertained. It seems likely that the form changed to some extent during the run, because as the value of R was varied the relative magnitudes of $I-i$ and i_1 (Fig. 12) changed and this would affect the form of e_p.

For various of the runs given in Table I oscillograms were taken of some or all of the quantities involved. For the conditions of run A the curves of e_p, e_g, and i_p are given in Fig. 24. From this film, as from the succeeding ones, the first thing to be noticed is that the grid voltage and plate voltage are just 180 degrees out of phase, showing that the load circuit was resistive only. The maximum positive potential of the grid measures on the film 296 volts and the corresponding value of plate potential measures 220 volts. By reference to the curves of Fig. 17 it may be seen that for these respective voltages a large part of the electron current is drawn to the grid, resulting in the peculiar double humped curve of plate current. The maximum negative grid potential was 650 volts, but even this was not sufficient to make the plate current zero. Its values follow, exactly as can be measured, the values given by the curve of Fig. 21. The slight deformation occurring on the positive alternation of E_g is due to the pulse of current taken by the grid at this part of the cycle; the wave form of the alternator used for E_g was nearly a pure sine wave, as may be seen from some of the other films to be given, in which the grid took no current.

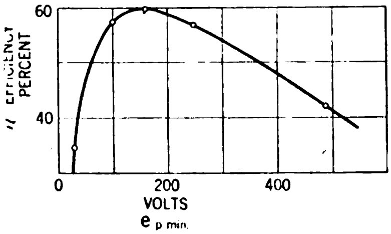


FIG. 23

For run B a set of oscillograms was taken to show all of the quantities involved in the operation of the tube; it required five oscillograph records to get all the quantities wanted. These five films were combined to make the record shown in Fig. 25; in fitting the various films together care was taken to see that they had their proper respective phases. The white line drawn vertically through all the records gives a line of equi-phase.

This set of curves gives the complete story of the circuit and tube. The plate current is very nearly the form shown in Fig. 20, and the plate potential is nearly of the form shown in condition (a) of the same figure. The slight depression in the peak value of i_p is due to the grid taking some current, this depression coinciding in time with the peak of grid current. The form of the positive alternation of the i curve is not like those previously given, due to the fact that it has been assumed that I_p was constant whereas it actually had considerable fluctuation, as shown in the record. If the coil used for L_1 had more inductance this variation in I_b would be diminished; we had only 10 henries with a resistance of 189 ohms, the coil being air core. In practise an iron core coil of greater inductance would be used but we did not want to introduce any other sources of distortion than the tube itself.

The form of current in condenser C_1 differs from that in condenser C_2 because of the effect of i_1, which will practically all flow through C_1 for the circuit as arranged.

The grid current has just the form and magnitude predictable from Fig. 17; the amount of current taken by the grid in this test and the values of E_g and E_c used caused a loss of power on the grid (due to bombardment) of about 10 watts.

The two filament currents i_f and i_f' have forms which might be predicted from curves similar to those given in Fig. 15; in that end of the filament carrying the large current the continuous current ammeter measuring the current indicated only 3.65 amperes whereas the current actually went as high as 3.99 amperes when the plate was taking its maximum current. The question comes up at this point as to how quickly the variation in emission from a filament can follow the changes in current; it would seem from our oscillograms that the emission follows current changes much more rapidly than one would think. This point is being further investigated.

The drop across the condenser C_2 was taken to see whether or not it had the right magnitude and phase to serve for excitation of the grid when the tube was run self-exciting; the value of C_2 had been adjusted with this point in mind.

The scheme of getting the efficiency indicated in Figs. 19 and 20 was tried on this record of e_p, i_p, and i, the power curves of $e_p\, i_p$ and $e_p\, i$ being shown in Fig. 25; the value obtained, 59 per cent, agrees within the precision of the test with that measured by the meters in the test. The value of 63.8 per cent given in Table I was the value obtained when the oscillograph circuits were not connected; the closing of the circuits changed the conditions enough to drop the efficiency to 59.5 per cent.

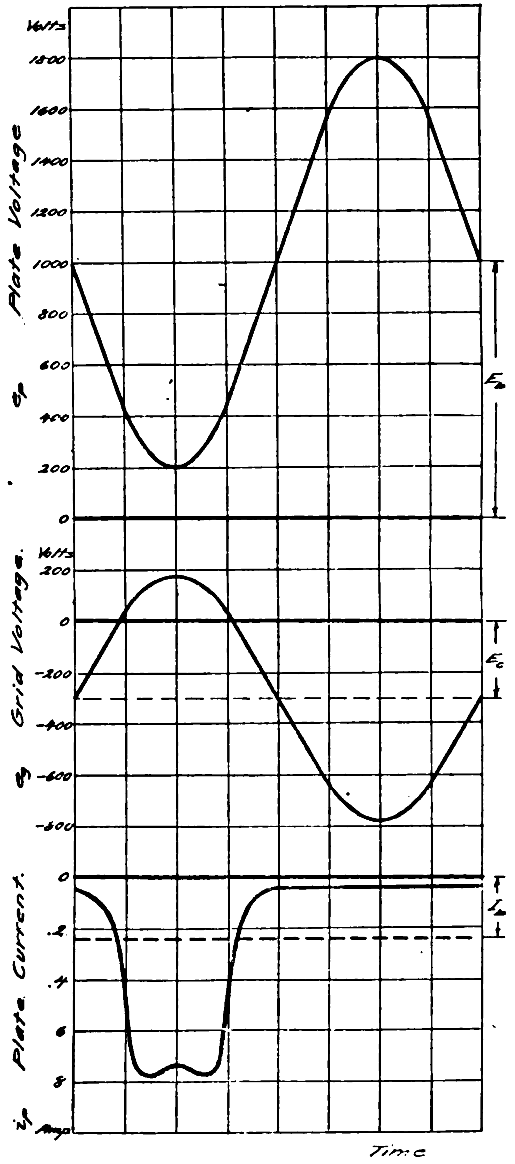


Fig. 26

Fig. 26 shows the form of i_p which is predicted from Fig. 17 after the forms and magnitudes of e_p and e_g have been assumed;

this form of i_p is very close to the actual form given in the oscillogram of Fig. 25.

The result of our tests and analysis have then shown that the efficiency of a tube as a generator can be accurately predicted from the three sets of curves given in Figs. 14, 17, and 21 after we have determined, from the curves of Fig. 17, what the best minimum plate potential is and also what the maximum positive potential of the grid should be.

To get a fair efficiency (60 per cent or better) the value of I_b should not be greater than 25 per cent of the saturation current of the tube; with the efficiency known and the safe radiation of power from the plate being known, the proper value of E_b is fixed.

Self Excited Tube. Using the circuit and constants used in getting the records of Fig. 25 an attempt was made to run the

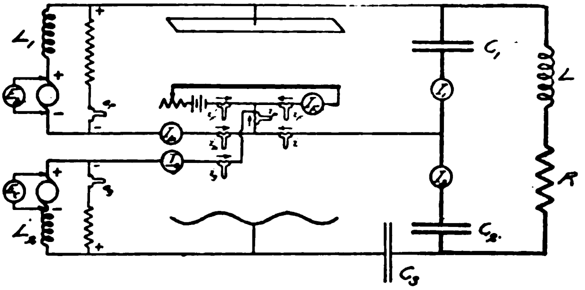
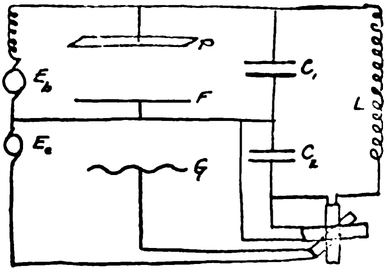


FIG. 27

tube self exciting by changing the connections slightly as shown in Fig. 27. The choke coil L_2 serves to prevent the grid from being short circuited to the filament (for the a-c. excitation) through the machine E_c. The voltage for excitation was obtained from the drop across the condenser C_2, the insulating condenser C_3 being necessary to prevent shortcircuiting the machine E_b. With this connection the grid does not get quite as much excitation as shown by the curve e_{c2} in Fig. 25, because an appreciable part of this voltage is used in overcoming the reactance drop in C_3. (In this calculation the capacity of the grid circuit of the tube itself must be considered; in some of the type P tubes this capacity is as high as 200 $\mu\,\mu\,f$. when the load circuit has its proper impedance for maximum output.)

The circuit of Fig. 27 refused to act as it did for the separate excitation, giving a small output at a low efficiency; a more careful examination of the record in Fig. 25 gave the reason. The alternating components of e_g and e_p must be exactly 180 degrees out of phase if the maximum output and efficiency are to obtain, as becomes at once evident if the construction of Fig. 19 be carried out for only other than the 180 degree relation. Measurement of the film of Fig. 25 shows e_{c2} to be 33 degrees out of the 180 degree phase with e_p and that much phase displacement is sufficient to completely upset the conclusions so far reached. It was therefore necessary to change the relative phases of e_p and e_{c2}. A possible scheme is conventionally indicated in Fig. 28; a rotating field is produced by proper connection to the load circuit and a rotatable coil placed in this rotating field serves for the grid excitation. We had a simpler scheme at hand so did not try this one.



Grid excitation at adjustable phase

FIG. 28

The difference in phase in the voltages across C_1 and C_2 comes from the effect of the current i, present in C_1 to a greater extent than in C_2. By making the effect of this current small its disturbing effect may be reduced, and this can be done by increasing the values of C_1 and C_2, the value of L being properly reduced to maintain the same frequency. The increase in capacity will increase the value of the oscillatory current i_1 and as i remains constant its effect on the relative phases of e_{c1} and e_{c2} becomes proportionately less as the capacity is increased.

The arrangement of apparatus remaining as in Fig. 12 the constants were readjusted for efficient operation and a set of readings were obtained as follows; E_b = 900 volts, E_c = 230 volts, E_g = 310 volts, frequency = 143, L_1 = 9.8 henries, I_b = 0.321 amperes, C_1 = 9.2 microfarads, C_2 = 18.4 microfarad. The resistance of the load circuit was 7.80 ohms and the oscillatory current produced was 4.30 amperes giving an alternating current output of 143 watts. The input to the tube circuit is obtained from the product $E_b I_b$ after certain losses, not chargeable to the tube circuit, have been deducted.

The condensers C_1 and C_2 each consisted of two condensers connected in series because of the high potentials occurring in the circuit. In order to make the two individual condensers divide the voltage E_b equally it is necessary that their insulation resistances be alike, a condition seldom encountered. That condenser having the higher resistance (the better one) will take all of the E_b voltage as well as its share of the alternating voltage of the circuit, resulting in its probable breakdown. To prevent this occurrence leak resistances were used across each of the condensers making up C_1 and C_2, the leaks each being 21,000 ohms making the leak resistance of C_1 and C_2 each 42,000 ohms. Subtracting the I^2R losses in these leaks as well as the $I^2 R$ loss in the choke coil L_1, gives the input to the tube circuit 229 watts; the efficiency was thus 62.7 per cent.

Oscillograms taken of the currents in this circuit are given in Fig. 29. It is evident that the values of E_g and E_c might well have been greater, resulting in a higher efficiency because of the resultant smaller minimum plate current. Although the plate current during the time $A - B$ (Fig. 29) is small, the plate voltage is large and so results in a high unnecessary loss on the plate.

The phase of E_{c_2} is now practically coincident with that of E_g and it should therefore serve as a source of excitation. The circuit did not give as much power however when made self exciting as it should so the constants were changed slightly to get more power. As finally tested the self-exciting circuit had the constants and performance given herewith: $E_b = 1000$ volts, $I_b = 0.335$ amperes, $C_1 = 7.36$ microfarads, $C_2 = 13.8$ microfarads, $L = 0.201$ henry, $L_1 = 9.8$ henry, $L_2 = 9.0$ henry $E_c = 230$ volts, $R = 8.0$ ohms. The current produced in the oscillating circuit was 4.40 amperes resulting in an efficiency of 57 per cent.

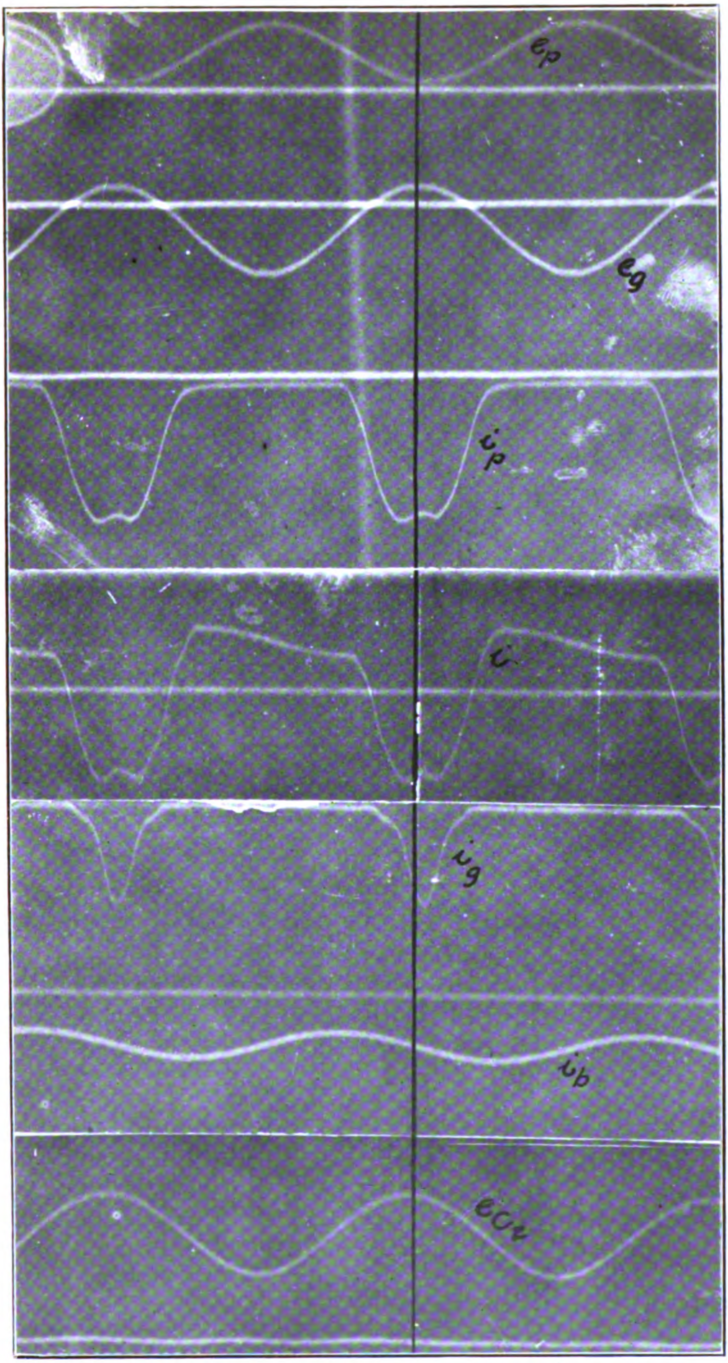
Fig. 30 shows the currents and voltages in this self exciting circuit and it is at once evident why such a low efficiency was obtained; the minimum plate voltage instead of being 200 volts, as it should for this tube, was 300 volts. For this figure the curve of plate current included also the grid current, hence the absence of the depression at the peak value.

The current through the plate current vibrator reversed during part of the cycle, due to the fact that this vibrator carried in addition to the plate and grid currents, an alternating current which resulted from the voltage across the condenser C_2 acting through the reactance of coil L_2 and condenser C_3, Fig. 27. This current is shown as i_x in Fig. 30; when the plate current is corrected by this small amount it is seen that the plate current does not reverse, as we know it cannot with the conditions as they existed in this test.

Action of the Tube at High Frequency. It was desired to show that the action of the tube was just the same at high frequency as at the low frequencies used, so a circuit was arranged similar to that of Fig. 27, with smaller values of capacity and inductance. The choke coils L_1 and L_2 used in the previous tests would act as condensers of comparatively low reactance at the high frequency to be used, so they also had to be changed. The constants of the circuit used were: $E_b = 1000$ volts, $I_b = 0.285$ amperes $C_1 = .0144$ microfarad, $C_2 = .0284$ microfarad frequency $= 98{,}500$, $L_1 = .023$ henry, $L_2 = .016$ henry, $E_c = 240$ volts, $R = 6.16$ ohms (high frequency determination). There were no leaks used with the condensers in this circuit so that the product $E_b I_b$ after subtracting the $I^2 R$ loss on the choke coil L_1, gives the input. It is found to be 284 watts, and as the output to the load circuit was 160 watts the efficiency was 56.2 per cent which is in fair agreement with the results obtained at 166 cycles.

In Figs. 31 to 35 are shown some special oscillograms of the plate current, plate voltage, and grid voltage, all for the separately excited tube with the circuit shown in Fig. 12; the conditions of the circuit are noted in connection with each film. The curves show the result of varying the excitation, resistance of the oscillating circuit, etc.

The conditions obtaining when Fig. 35 was taken show the best adjustments for efficiency which we were able to get with the type P tube; the high efficiency was obtained without unduly decreasing the output. If this form of plate current could be maintained and the value of E_b be increased to 3000 volts the calculated efficiency becomes 85 per cent; this is probably as good as could be done with sine wave shapes of e_p and e_g but it seems as though, by suitably deforming both



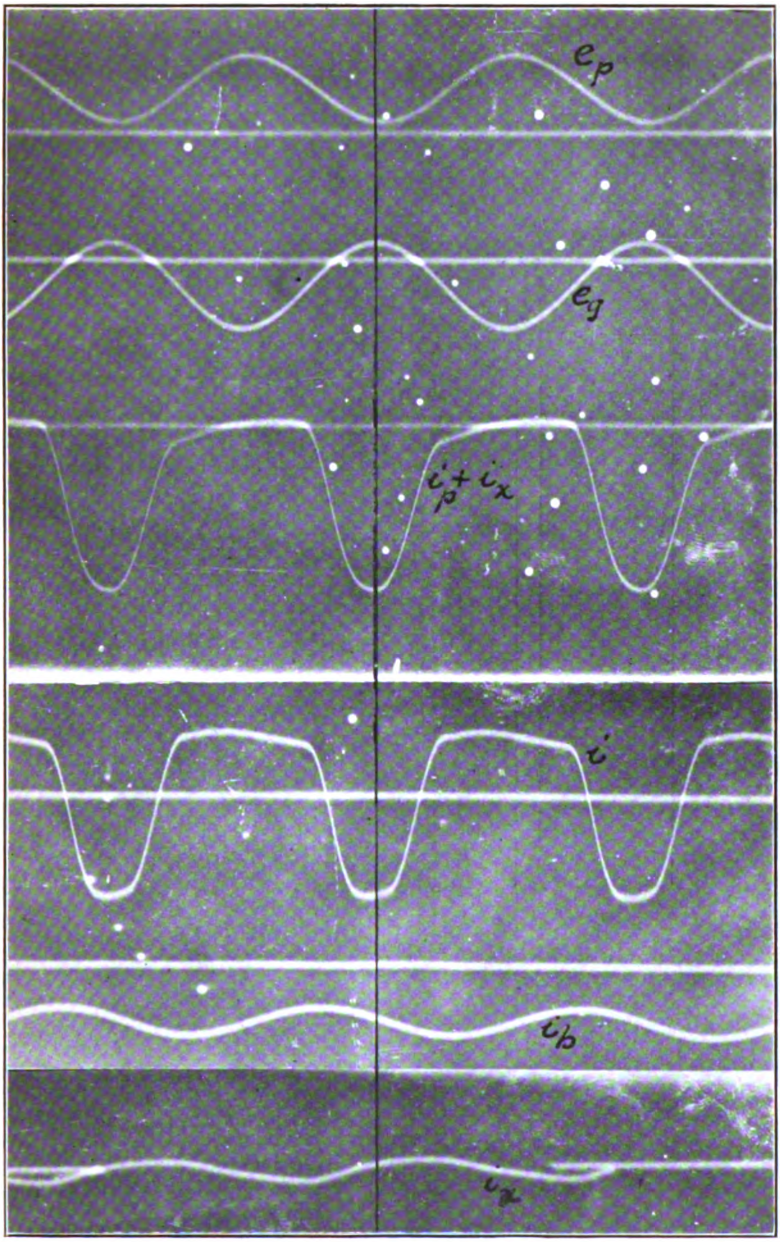
[MORECROFT & FRIIS]

$E_b = 940$ $I_b = 0.310$ $E_c = 230$ $E_g = 310$

$R = 7.80$ $I_2 = 4.30$

INPUT = 229 OUTPUT = 143 EFFICIENCY = 62.5 PER CENT

FIG. 29



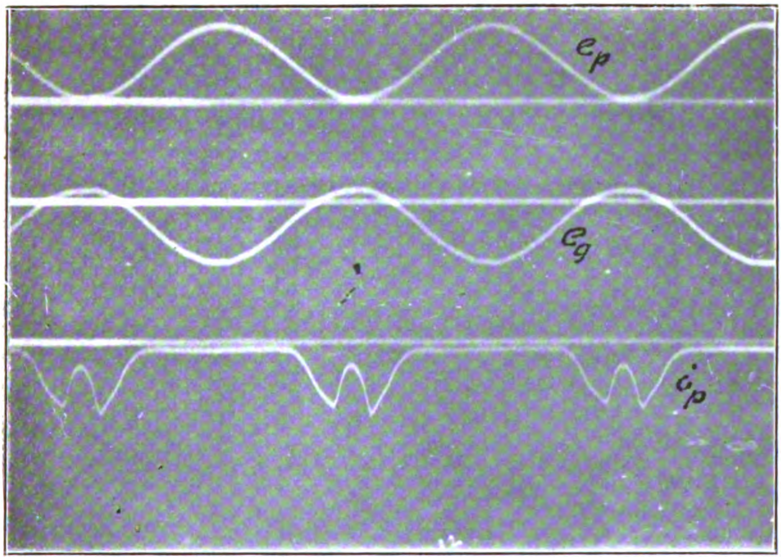
[MORECROFT & FRIIS]

$E_b = 1040 \quad I_b = 0.335 \quad E_c = 230$

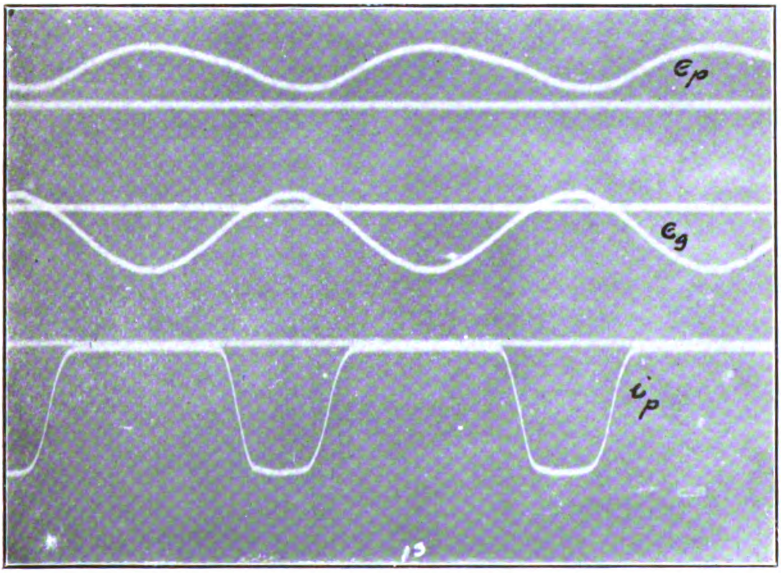
$R = 8.00 \quad I_2 = 4.40$

INPUT = 272 OUTPUT = 155 EFFICIENCY = 57 PER CENT

FIG. 30

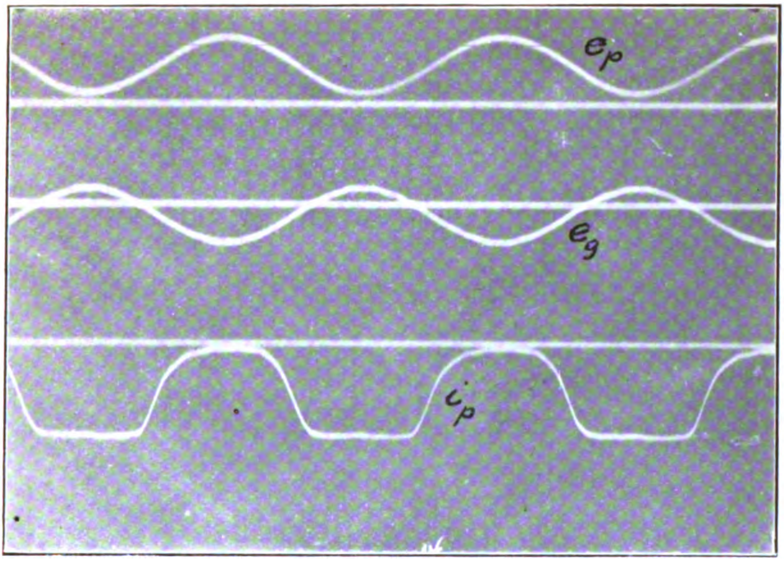


$E_b = 1040$ $I_b = 0.170$ $E_c = 270$ $E_g = 300$ $R = 37$
INPUT = 106 OUTPUT = 50 EFFICIENCY = 47 PER CENT
FIG. 31

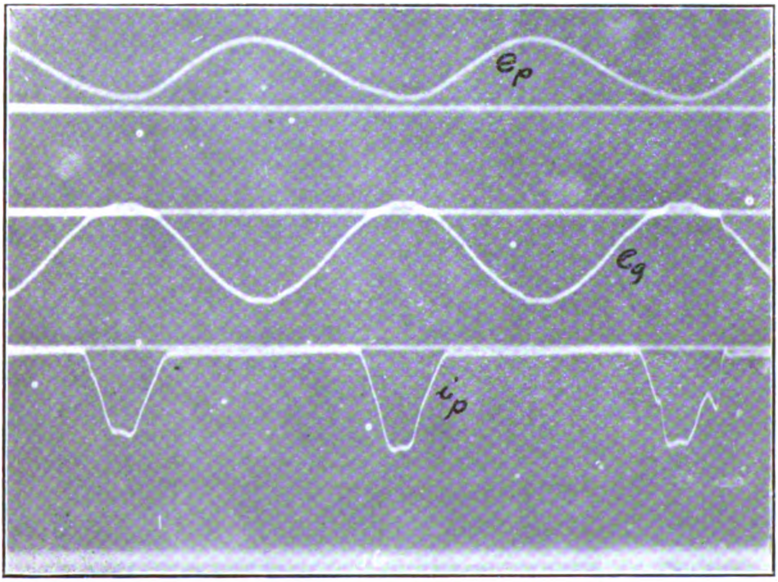


[MORECROFT & FRIIS]

$E_b = 1040$ $I_b = 0.330$ $E_c = 270$ $E_g = 300$ $R = 297$
INPUT = 274 OUTPUT = 108 EFFICIENCY = 39 PER CENT
FIG. 32

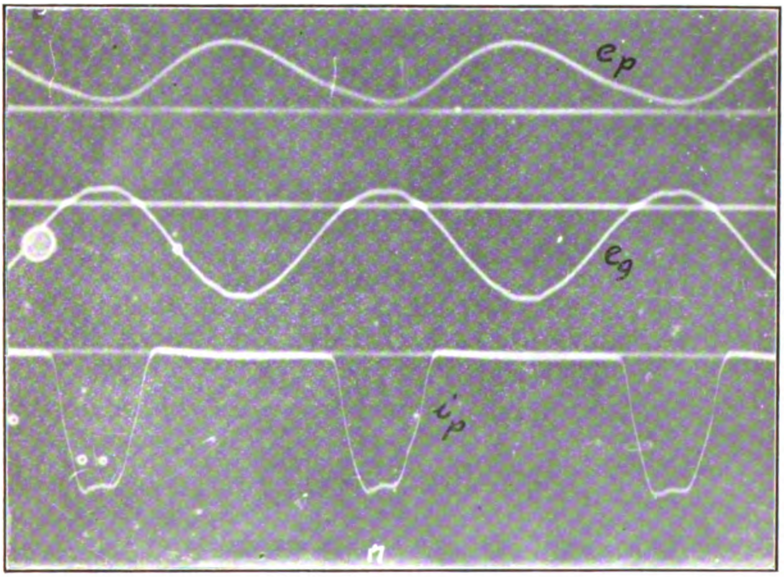


$E_b = 1040$ $I_b = 0.385$ $E_c = 120$ $E_g = 220$ $R = 149$
INPUT = 332 OUTPUT = 132 EFFICIENCY = 40 PER CENT
FIG. 33



[MORECROFT & FRIIS]

$E_b = 1040$ $I_b = 0.178$ $E_c = 450$ $E_g = 400$ $R = 74$
INPUT = 115 OUTPUT = 71 EFFICIENCY = 62 PER CENT
FIG. 34



[MORECROFT & FRIIS]

$E_b = 1040 \quad I_b = 0.286 \quad E_c = 410 \quad E_g = 460 \quad R = 149$

INPUT = 227 OUTPUT = 155 EFFICIENCY = 68 PER CENT

FIG. 35

of them, the efficiency could be considerably increased over this figure.

Tests similar to those described in this paper were carried out using a much smaller tube, that styled by the Signal Corps VT-2. The results obtained with the large tube were duplicated almost exactly in so far as efficiency was concerned. Although the normal adjustments used with these tubes were such that the tube efficiency was about 30 per cent it was found possible to so adjust the values of E_c and E_g that the tube gave an output of 6.3 watts with an efficiency of 70 per cent the voltage used in the plate circuit being the rated value, namely 300 volts. It was found possible to get over 7 watts output with the plate loss considerably lower than its safe rated value; if the plate voltage had been increased to perhaps 400 volts the tube output might have been raised to 10 watts while still having the plate loss within its safe value.

These tests were all carried out with a separately excited tube; with the tube self excited the efficiency was not obtained higher than 61 per cent, with a plate voltage of 300. This run gave an output of 5.6 watts output with a current I_b of 0.0305 amperes; the frequency was 400,000 cycles, the value of R was 53 ohms, the oscillating current 0.325 amperes, C_1 and C_2 being 1360 and 770 micro-micro-farads, respectively. The value of E_c was 40 volts.

With the conditions of a self excited circuit adjusted for the best conditions as previously outlined difficulty may be encountered in starting the circuit to oscillate, a shock of some kind being generally required to start oscillations. Because of this possible difficulty it may be the best practise to run tubes separately excited, using one tube, (so adjusted that it oscillates readily) for exciting others. It may well be that with a high resistance in the oscillating circuit more output can be obtained from two tubes if one only is used as a generator, the other being used as exciter only. Certainly if more than two tubes are to be used it will be well to use one as exciter for supplying the grid voltage for the others.

Somewhat more manipulation is required with the separately excited tube than with the self excited one because two circuits (the resonant circuit of the exciter and the output circuit of the power tubes) must be tuned, but the probable increase in output will make it worth while.

To be presented at the 355th meeting of the American Institute of Electrical Engineers, New York, November 14, 1919.

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PRESENT LIMITS OF SPEED AND POWER OF SINGLE SHAFT CURTIS STEAM TURBINES

BY ESKIL BERG

Abstract of Paper

This paper starts by showing that the limit of a single-unit turbo generator does not lie in the generator but is confined to the steam turbine, and that the last wheel of the turbine is the limiting feature.

The author therefore takes the last wheel of an 1800-rev. per min. turbine, giving dimension stresses, kind of material used etc., and then designs two turbines, one having 23 stages and the other 13 stages, both machines using this last wheel, and shows that a turbine can be built having its most economical point at 21,000 kw., under steam conditions given in the paper.

Under this condition the last stage absorbs 11.5 per cent of the total adiabatic available energy, and the wheel efficiency is 66.25 per cent. As the load increases, the work done in this stage also increases, so that at 36,000 kw. the energy is practically doubled, but with a sacrifice in efficiency of about 18 per cent, which naturally lowers the efficiency of the turbine as a whole.

A 5000-kw., five-stage, 3600-rev. per min. turbine load curve is also given and discussed, and the author claims that if the construction could be made similar to the large turbine, keeping the same stresses and number of stages, a turbine of this capacity could be built as efficient as the larger machine at 20,000-kw.

THE purpose of this paper is to discuss the limitations of the types of turbines used in the more important work now done by the General Electric Company, and to show the relative results which can be accomplished with such designs under different conditions of load. Different mechanical arrangements will make practicable different characteristics, and the conditions shown only apply to machines of these particular designs. The design of turbines must be governed by many compromises and it would not be possible to give a correct idea as to the whole range of possibilities.

For purposes of illustration, two machines have been selected, one representative of the largest size built for 1800 rev. per min. and one of the largest size now built for 3600 rev. per min. The figures given relate to the turbine alone, and do not include generators. The generators used with such turbines might be designed for various power factors or overload capacities, and would thus be of different efficiencies.

The turbines in question are both of the single-flow type and may be considered representative of capacity limitations of that type, since their construction is that which is adapted to the highest capacity. The single-unit turbine and generator is naturally preferable over the tandem and compound type on account of simplicity, lightness, and efficiency. There are however certain definite limitations in the size for a given speed that these units can be built with material available at the present time. The limitation in the size of a unit for a given speed does not depend upon the generator, but is entirely dependent upon the turbine.

Fig. 1 shows the load curve of the large 1800-rev. per min. machine above mentioned, which is designed to operate with 250 lb. steam pressure, 28.5 inches of vacuum, and dry steam. This turbine has 23 stages, all wheels being of the single-bucket type. The first stage wheel has a pitch diameter of 35 inches, which increases with each successive stage until the last wheel, which has a pitch, diameter of 88 inches. This curve shows that for 1800 rev. per min., a turbine can be designed for a vacuum of 28.5 inches, giving its best efficiency at 21,000 kw., this point being marked on the curve by 1, and the water rate at other points being given in proportion to this point. This curve also shows that with a sacrifice of 5 per cent in efficiency, an output of 36,000 kw., can be delivered to the turbine shaft. Above a load of 21,000 kw., live steam is bypassed to the eighth stage shell, the effect of which is shown by the break in the curve.

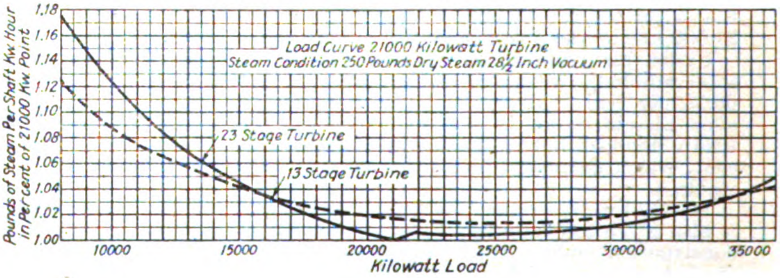

FIG. 1

The dotted line gives the load curve of a similar turbine in which the first eleven stages are replaced by one two-bucket stage. This turbine is designed with multiple valve steam admission. Such a modification may be desirable for the purpose of simplification, or where better efficiency at very light loads is important, as in the case of propulsion of warships.

Fig. 2 gives the vacuum curve of the 1800-rev. per min., 23-stage machine at 21,000-kw. and 36,000-kw. load on the turbine shaft. It will be noticed that the improvement in economy at a load of 21,000 kw., is 2.5 per cent between 28.5 and 29 in., whereas with a load of 36,000 kw., due to congestion of the steam passages, the gain is only 0.55 per cent.

Many large size turbines are now designed for a vacuum of 29 in. The volume of one pound of steam at this vacuum is 652 cu. ft., almost 50 per cent greater than at 28.5 in., and about twice as much as at 28 in., which calls for a corresponding increase in the area of the steam passage in the last stage wheel. If this area is made too small, the steam when leaving the last row of buckets must have a high velocity, which gives a large loss of energy, this loss being in proportion to the square of the velocity. It is therefore important that this area be made as large as possible, and that the exit angle of the blades be made small enough to give good extraction.

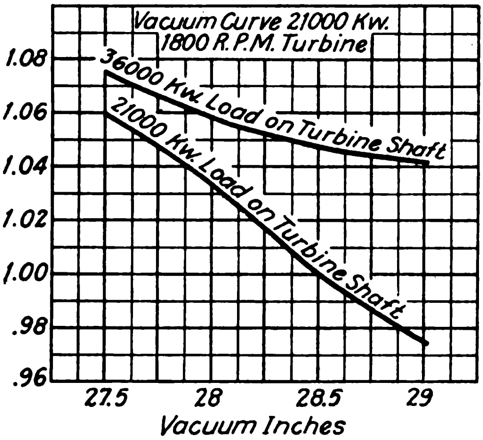

FIG. 2

Efficient action can only be accomplished by using a bucket speed that bears a proper relation to the steam velocity. Consequently to get the largest capacity we must not only use long buckets, but must move them at a very high speed. In order to obtain good bucket action, the buckets should not be more than about one fourth as long as the pitch diameter of the wheel. If they are made longer than this, poor bucket action with consequent loss in efficiency will result, due to the great difference in peripheral speed between the base and the tip of the bucket, the design being made correct for the middle point or pitch line. The flare also becomes excessive, so that the space between the buckets at the tip will be so large that steam can flow between the buckets without doing any work.

The use of a high steam speed in this last stage naturally implies that a relatively large proportion of the total steam energy must be utilized there, and such concentration of work into a single stage is not without its disadvantages, since even if the best relation of velocities is maintained, such a stage doing a large amount of work is naturally less efficient than a stage of similar character doing less work.

Since for the reasons given above, the design of the last stage in such a turbine constitutes the most important limitation, we will consider some details of the design used in this case. Fig. 3 represents the last wheel of the large 23-stage 1800-rev. per min., turbine which has been mentioned. This turbine is designed to operate at 250 lb. steam pressure, 28.5-in. vacuum, and dry steam. The pitch diameter of the wheel is 88 in., length of buckets 22 in. and bucket angles 60 deg. entrance and 40 deg. exit. The wheel is subject to the following stresses at normal speed:

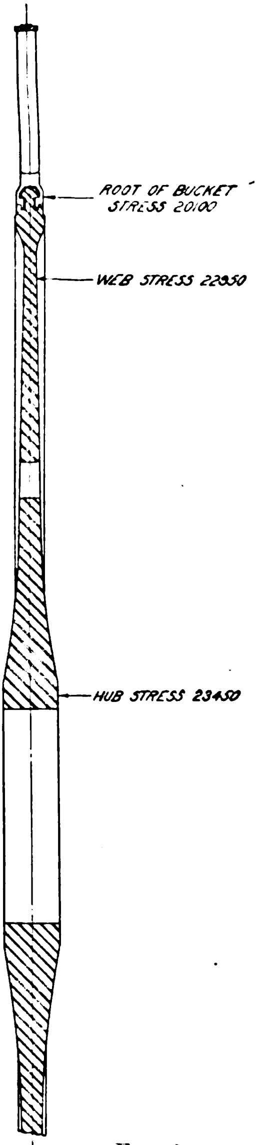

Fig. 3

Stresses in hub, 23,450 lb. per sq. in.
Stresses in web, 22,950 lb. per sq. in.
Stresses in bucket, 20,100 lb. per sq. in.

Elastic limit, (limit of proportionality) of material, 55,000 lb. per sq. in. The material of the wheel and bucket is quenched and tempered 3 per cent nickel steel.

The wheel is stiff enough to avoid vibration effects, and in the absence of such effects the centrifugal strains afford ample factors of safety, even if we assume considerable irregularities and imperfections of metal structure.

CAUSE OF WHEEL BREAKAGES

In some of the first large machines of the type here discussed, very serious trouble has developed through the formation of cracks in the forged wheels. Such cracks have caused wheels to break in three important installations. The cracks which have formed in these wheels have started at holes in the wheel provided either for balancing steam pressures on the two sides of the wheel, or for the attachment of balance weights. The occurrence of these accidents naturally gave rise to much alarm, uncertainty, and difference of opinion as to the cause of the trouble. Calculation showed that the wheels which broke were less stressed than many which were made from weaker metal and had operated for long periods of time. Holes in a centrifugally stressed wheel greatly increase the fibre stress in the vicinity of the hole itself, but such conditions had not caused the formation of cracks in large numbers of wheels in which such localized high stresses existed. Many evidences have now shown that the trouble with these wheels has not resulted from stresses in excess of those which had been previously found to be practicable, but has been caused by fluttering and vibrations of the wheels, which had become possible through the lightness and thinness of their construction. Such vibration give a periodic character to the stresses normally imposed and so give rise to the formation of fatigue cracks.

In machines of this type relatively light and narrow buckets have been used, and the wheels have been proportioned with a view to ample centrifugal strength, but with maximum economy of space and weight, consequently these wheels have had much less lateral stiffness than wheels used in turbines of previous types. To overcome such troubles as have developed, it is simply necessary to make the wheels stiffer and to put in holes in parts of the wheel near the hub where a suitable reinforcement of thickness can be provided which both stiffens the wheel and reduces stresses near the holes. Very slight changes of this kind make a great difference in the vibrating characteristics of such wheels, and the proportions used are such that they can easily be brought to the same standards of safety in these respects as have long prevailed in wheels of heavier construction in machines having less numbers of stages.

Experience has shown that in the absence of a tendency to form fatigue cracks through vibration, overspeed in such turbine wheels involves relatively little danger as compared with other types of high-speed machinery. Experimentally and in actual service, wheels have been stretched to a considerable degree of enlargement without the formation of any cracks, and such stretching is a normal condition if the cracks do not exist.

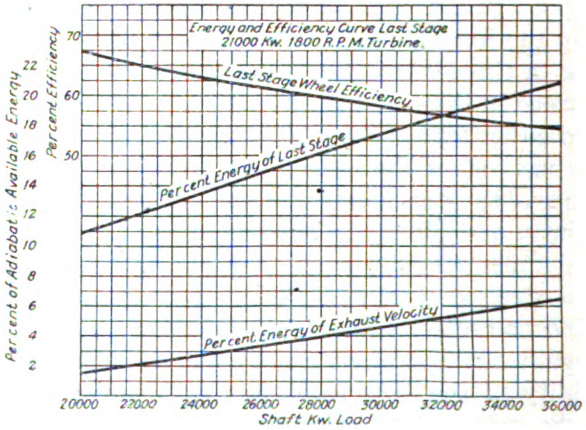

FIG. 4

It has been discovered that such fluttering or vibration of the web of wheels has not only been responsible for the formation of fatigue cracks in the wheels themselves, but has also caused loosening and breakage of buckets. The cure for these difficulties is to use stiffer wheels, and such wheels can carry stiffer buckets, so that the whole structure is incapable of vibration of any amplitude through such forces and periods as arise from the conditions of operation.

Fig. 4 gives the energy and efficiency curves of this last stage. It will be noticed that at the most efficient point, (21,000 kw.), this stage absorbs 11.5 per cent of the total adiabatic available energy, and that the wheel efficiency is 66.25 per cent. The energy represented by the exhaust velocity which is all wasted in the condenser is 1.5 per cent of the total energy. As the load increases on the turbine shaft, the energy in this stage also increases, decreasing its efficiency until at 36,000 kw. the energy in the last stage is 20.9 per cent of the total energy. The wheel efficiency however has been reduced to 54.2 per cent and the energy represented by the exhaust velocity has been increased to 6.4 per cent. This great amount of work in the last stage at such poor efficiency naturally lowers the efficiency of the whole turbine, and in this case the efficiency at 36,000 kw. is 5 per cent lower than at 21,000 kw.

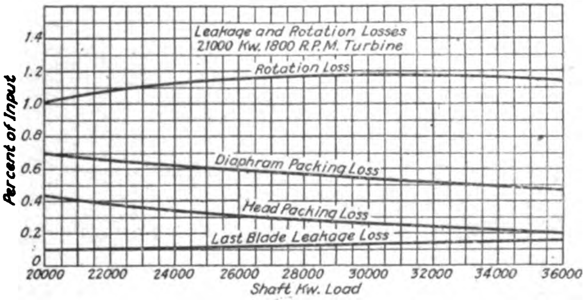

FIG. 5

Fig. 5 shows leakage and rotation losses of the same turbine in per cent of input.

From the above it will be seen that for 1800 rev. per min., a turbine can be designed efficiently for 21,000 kw. which, with a sacrifice of efficiency can deliver 36,000 kw.

Fig. 6 gives a load curve of the smaller 3600-rev. per min. turbine. The water rates are here given in reference to that of the larger machine, the load of 5000 kw. corresponding to that of 20,000 kw. on the 1800-rev. per min. turbine. This turbine has only five stages, one two-bucket wheel in the first stage, the other four stages having single-bucket wheels. The first wheel has a pitch diameter of 35.5 in., and the remaining four wheels a pitch diameter of 51 in. The bucket height of the last wheel is 9.125 in., the turbine being designed for a maximum of 6250 kw.

The reason for such a discrepancy in the number of stages calls for explanation. As the output of a turbine, keeping approximately the same stresses, goes up inversely as the square of the rev. per min., if the same number of stages could be used and clearance and all dimensions proportionately reduced, a 5000-kw. machine at 3600 rev. per min. could be made nearly as efficient as a 20,000-kw. machine at 1800 rev. per min., and developments of smaller multi-stage machines at our Lynn Works have already been made which approximate such possibilities. Constructions however which are practicable on a large scale are not practicable on a small scale, and consequently there are difficulties in getting the space economy in small high-speed machines which would be necessary for accomplishing the result stated. One of the difficulties has lain in the construction of diaphragms, the casting in of nozzle partitions being easy in a large diaphragm and very difficult on a small one. We are working upon types of diaphragms and other parts which may make possible the development of multi-stage high speed machines which afford improved degrees of economy.

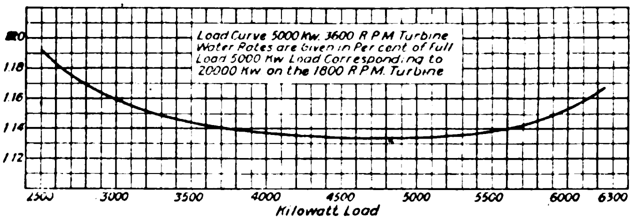

FIG. 6

If a 10,000-kw. turbine is designed for 1800 rev. per min., the only change necessary would be to make the nozzle and bucket heights about half the height of those in the 20,000-kw. unit. This reduction in height of buckets and nozzles would affect the weight, size, and cost of the turbine very little as compared with the 20,000 kw. unit. In regard to economy, the lower bucket heights would reduce the rotation loss somewhat but far from 50 per cent. The diaphragm packing loss, head packing losses, and bearing losses would be practically the same as on the 20,000-kw. unit, so that while a turbine designed for 10,000 kw. would be more economical than the large turbine running at half load, the difference would be small, being only about 6 per cent.

It will be seen from this paper that for a given speed there is one particular size of turbine which can be designed to be most economical as to steam consumption, weight, space, and price per kilowatt. Even if a size smaller than this is required, it would in many instances pay for the central station to install the larger unit, even though it would have to run at reduced load for some time before the station load increased sufficiently to utilize the full capacity.

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PRESENT LIMITS OF SPEED AND OUTPUT OF SINGLE-SHAFT TURBO GENERATORS

BY F. D. NEWBURY

ABSTRACT OF PAPER

Output is determined broadly by rotor or stator dimensions. With speeds of 1200 rev. per min. and lower, the stator is the limiting member, while with higher speeds, the rotor is the limiting member.

The most effective rotor diameter is not necessarily the largest diameter. To obtain maximum output at a given speed the rotor proportions must be chosen to properly balance mechanical stresses, rotor ampere turns and flux. American design practise has established 400 ft. per sec. as an upper limit of rotor peripheral speed.

The maximum length of core is determined by such factors as ventilation, bearing temperatures, critical speed and limits to weight imposed by forging and transportation facilities.

Fig. 4 shows present limits to kv-a. rating at speeds from 3600 to 900 rev. per min. These limiting values are given as indicating present boundaries to knowledge and experience, rather than as real physical or other limits that cannot be exceeded.

Mechanical forces due to short-circuit current, and damage caused by armature winding failures, are no greater in the very large generators indicated by Fig. 4 than in present day 20,000 and 30,000 kv-a. units.

No opinion is expressed as to the wisdom of installing very large single-shaft units. If operating engineers desire units of 50,000 to 100,000 kw., there is no question but that such generators can be conservatively designed and constructed.

REDUCED to the simplest terms, maximum output at any speed is attained when slot space is provided for the maximum possible ampere turns (in either stator or rotor), and core cross section is provided for the maximum possible flux. These conditions require the most effective rotor diameter (or stator bore) and the maximum rotor and stator core length. All factors that limit rotor diameter (or stator bore) or core length have a possible bearing on limiting outputs.

The most effective rotor diameter for a given speed is not necessarily the largest diameter. For maximum output, the rotor should have maximum space for winding and maximum tooth and core section for flux. Obviously, these requirements are antagonistic and the actual design is a balance between slot area and tooth and polar area. Again, as the diameter is increased (with a given speed) there is more room for both winding and flux, but with increase in diameter each pound of copper exerts an increasing centrifugal force and the ratio of slot area to tooth cross section must be decreased in order to keep within desired stresses. Beyond a certain peripheral velocity, ampere turns must be decreased, in spite of the increase in available space, and the most effective diameter has been passed. It is seen, therefore, that in order to obtain maximum output at a given speed, the rotor proportions must be chosen to properly balance mechanical stresses, rotor ampere-turns and flux.

Turbo generator design has settled down to one type of rotor, so far as form is concerned. This is the so-called radial slot type, in which the ends of the winding project beyond the core body. This construction is shown in Fig. 1, indicating the slot arrangement. This type of design requires solid rings of very good material for holding these projecting coil ends. The hoop-stress in the coil retaining rings is an important limit to output, and is, in fact, a more important limit than the tooth stress in the main rotor body.

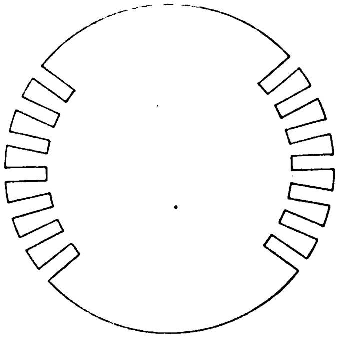

Fig. 1

In a large-diameter low-speed turbo generators (1200 rev. per min. and below) it is generally possible to employ a larger rotor diameter and more rotor ampere turns than can be properly balanced by stator ampere turns. The density of stator ampere turns is limited by the ability to dissipate heat (with permissible temperature differences) and by the permissible concentration of ampere turns in a single slot. Obviously, there is no such rigid limit to weight or depth of copper in a single slot in the stator as is imposed by centrifugal stresses in the rotor, but there is a limit to the depth of stator slots determined by the rapid increase in eddy current losses with deep slots and by the ability to construct and insulate long coils having a very large ratio of depth to width.

Thus, in certain cases the rotor is the limiting member and in other cases the stator is the limiting member. In general, the rotor first reaches its limit in ratings of 1500 rev. per min. and higher speeds, and the stator first reaches its limiting output in ratings of 1200 rev. per min. and lower, considering commercial frequencies.

It is apparent that unless the ratio of rotor ampere turns to stator ampere turns is a fixed design relation, all generators could be designed for the maximum possible output as determined by the stator, and the rotor need never be the limit. As a matter of fact, there is a tendency in this direction, the restraining fact being that as the field is weakened, relatively to the armature, the increase in field current and exciting voltage as the load is increased becomes greater. A reasonable limit to increase in excitation with load is desirable from the standpoint of voltage regulator operation. Regulators can readily handle a range of one to two or one to two-and-a-half, and large generators are proportioned to meet this ratio of no-load to full-load excitation. Voltage regulation has ceased to be a limit to output. These field and armature proportions result in regulations of roughly 25 per cent at 100 per cent power factor, and 40 per cent at 80 per cent power factor. Obviously, such regulations could not be tolerated if regulation were a factor in operation.

A fundamental difficulty in laying down definite limiting outputs is the difficulty in arbitrarily stating limiting stresses. The two principal stresses in the radial slot rotor are the tooth stresses in the main rotor body and the hoop stress in the coil retaining rings. Soft carbon steel is employed for the main rotor body, and a good quality ductile alloy steel (usually chrome-nickel or chrome-vanadium) is used for the coil retaining rings. Turbo generators are designed for a maximum speed 20 per cent above the running speed. At this over-speed, the tooth stresses should be approximately one-fourth the ultimate strength of the carbon steel and the coil-retaining ring stress should be approximately one-third the ultimate strength. This results in working stresses, in both cases, approximately half the yield point. It is important that the material be ductile; carbon steel with proper working, can readily be obtained with 22 per cent elongation and 35 per cent reduction in area and the alloy steel should have 22 per cent elongation and 50 per cent reduction. These figures refer to standard two-inch test pieces under tension.

American design practise has established 400 ft. per sec. as an upper limit of peripheral speed for maximum ampere turns and output for rotational speeds of 1500 rev. per min. and higher. This, of course, assumes existing rotor materials and factors of safety.

It is apparent that having increased the rotor diameter to the most effective value, output will be proportional to the length of the rotor and stator cores, and maximum output will be secured when the length is increased to its limiting value. This limit to length is even more a matter of opinion and judgment than is the limit to rotor or stator diameter. It is determined mainly by cooling air requirements, by bearing proportions, by limits to weight imposed by transportation facilities and the ability to secure forgings of necessary diameter and weight.

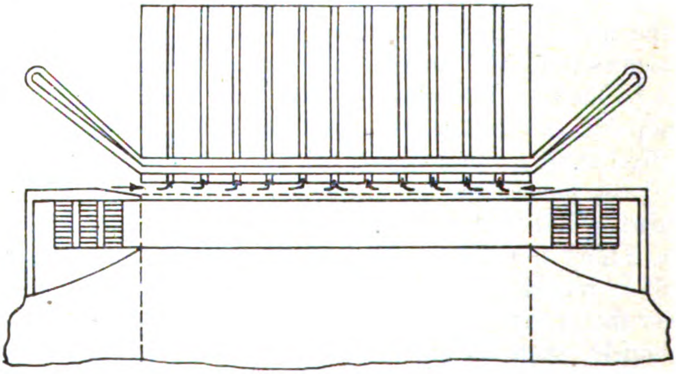

Fig. 2

Ventilation. The generator losses, and consequently the required volume of cooling air increase almost in proportion to the core length. In the simple radial or air gap system of ventilation, shown diagrammatically in Fig. 2, all of the cooling air must pass through the air gap entering the annular openings between stator and rotor at the two ends of the generator. The radial dimension of the airgap is constant with constant rotor diameter and consequently the volume of cooling air can only be increased as the core length is increased by increasing the air pressure.

Also, as core length is increased, the diameter of the shaft extension of the rotor body must be increased and the fan intake becomes restricted. In the axial system of ventilation, illustrated in Fig. 3, the stator ventilation is taken care of independently of the air gap and the requirements as to cooling air becomes less important from the standpoint of limiting output. But with either system of ventilation, designers are already finding it necessary to devise more complicated systems in order to take care of 3600 and 1800 rev. per min. ratings now in prospect.

Rotor Deflection. As the core length is increased, necessitating an increased distance between bearings, the rotor deflection increases. This increases the reversing stress in the shaft material at the journals and reduces the value of critical speed. As the core length is increased, the journal and bearing sizes must be increased in order to keep the shaft stress and the critical speed within desired limits and a limit may be imposed by bearing losses and temperatures.

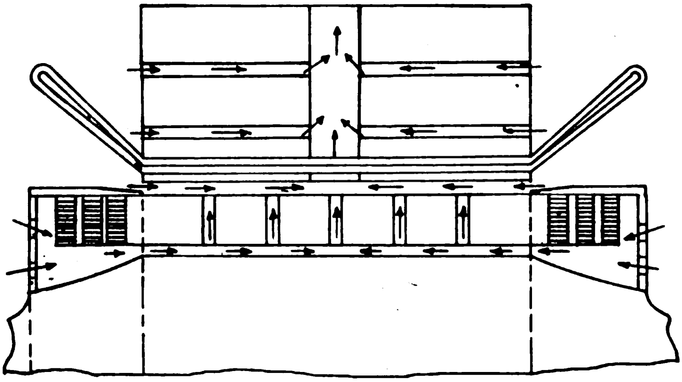

FIG. 3

Winding Temperatures. The limiting ratings given in this paper are based on 150 deg. total rotor winding temperature and from 125 deg. to 150 deg. total stator winding temperatures. It is not probable that ratings will be increased by increasing these temperature limits. Higher temperatures would be of most value in connection with the rotor winding since the rotor limits rating in the two- and four-pole designs commonly used. But temperatures higher than 150 deg. result in relatively little gain in rotor ampere-turns on account of the rapid increase in resistance of the winding. If the rotor winding temperature rise is assumed proportional to the loss, an increase in operating temperature from 150 deg. to 250 deg. (an increase in measured rise from 100 deg. to 200 deg.) results in an increase in ampere turns of only 25 per cent.* Thus doubling the temperature rise and rotor loss results in a gain of only 25 per cent in output.

Temperatures much above 150 deg. in connection with very long rotors are not considered favorably on account of the danger of trouble from "creeping" of the winding caused by linear expansion.

Transportation facilities may impose a limit to size in the case of six- and eight-pole 60-cycle generators. With the larger two-pole, 25-cycle and four-pole, 60-cycle generators now being built, the stators are now too heavy for convenient handling and transportation, and they are assembled in place at the power station. Rotors, from the special nature of their design and the special skill and equipment required for winding and assembling, should be completed at the builder's factory and shipped as a unit. The weight of the complete rotor of a four-pole, 1800-rev. per min. generator of 40,000 kv-a. capacity will be roughly 90,000 pounds. This can be transported without difficulty, but the largest possible 1200-rev. per min. rotor would weigh more than 200,000 pounds, and would require rolling stock and trackage (in some cases) not now available.

Another general limitation to output that applies to the larger diameter rotors is that imposed by the *forging facilities* of the country. At the present time it is not possible to obtain forgings of suitable physical characteristics weighing more than 50 to 60 tons nor much larger than 50 inches (assuming a minimum amount of working down from a 72-in. ingot). This limits the rotor, made from a *single* forging, to an output of roughly 50,000 kv-a. at 1500 rev. per min., and a proportionately decreasing kv-a. at lower speeds, assuming a solid rotor. By adopting the rotor construction involving two or three inch plates and up-set flanged shaft ends, the limiting diameter may be increased sufficiently for the largest 1500- and 1200-rev. per min. outputs, shown by Fig. 4. The design of 1200- and 900-rev. per min. generators for maximum output will be governed by questions of forging and shipping facilities, rather than by more strictly design matters.

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*A discussion of this point is contained in the author's paper, "Rational Temperature Guarantees for large A-C. Generators", TRANSACTIONS for 1916, Part I, Page 1497.

Fig. 4 shows in curve form limiting generator capacities at various speeds. At 1500 rev. per min. and higher, the capacity is determined by the rotor and is inversely proportional to the rev. per min. squared. At lower speeds, the capacity is limited by the stator and falls somewhat below the corresponding rotor limiting capacity as indicated by the dotted extension of the rotor curve. This curve is actually based on constant core length, when, as a matter of fact, the length can, with reason, be increased as the diameter is increased. The curve ratings, however, represent maximum lengths of core so far employed, and material extensions in core length involve questions of linear expansion that must be very carefully considered. This limiting capacity curve represents capacities that can be obtained with existing commercial materials and without radical changes in stresses and bearing proportions. The curve does not represent limits that may not be exceeded in the future. It is, more properly, an indication of present boundaries—boundaries that will be extended as our knowledge and experience are increased. It represents also the present judgment of designers, a judgment influenced greatly by the economic and operating advantages of still larger ratings.

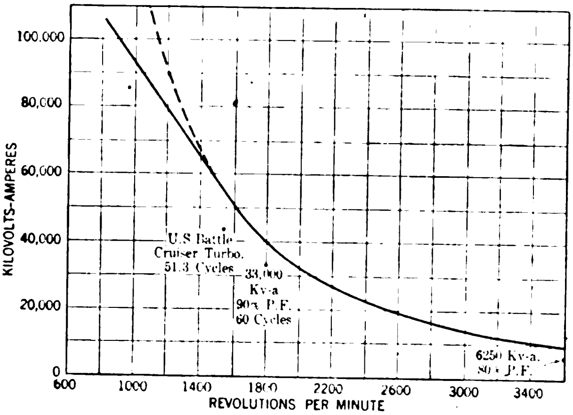

FIG. 4

The capacities shown by the curve are somewhat in advance of accomplished results. Ratings of several turbo generators that are the largest that have been placed in operation or are under construction by the Westinghouse Electric and Manufacturing Company have been added to Fig. 4 with self-explanatory comment.

As previously explained, the limiting capacities given for speeds below 1500 rev. per min. can only be attained by exceeding present transportation facilities if present design types are adhered to.

Incidentally it is interesting to note the advantage in limits gained by the use of 50 cycles as compared with 60 cycles. An increase of nearly 50 per cent in rating is made possible by the 20 per cent decrease in two-pole and four-pole speeds. This is of interest mainly when European and American maximum ratings are being compared.

The bare mention of ratings larger than 50,000 kv-a. raises the question of limits to size of individual generating units imposed by operating considerations, such as the relation between unit and station rating, the extent of the damage in case of winding failures, ability to withstand sudden short circuits and so on.

While the detailed discussion of these questions is beyond the scope of the present paper, some design information affecting operating questions may be of interest.

There is no reason for considering the larger low-speed generators less reliable than the high-speed generators indicated by limiting curve of Fig. 4. As a matter of fact, the lower speed ratings can usually be designed, both in stresses and in electrical factors, with more margin.

Mechanical forces developed by short circuits are determined by the short-circuit ampere turns of the armature winding per inch of armature circumference—and, to a limited extent, by the density of the magnetic field set up by the rotor winding. Both the distribution of ampere turns and the density of the airgap magnetic field are substantially constant for all limiting ratings of a given frequency. While the forces developed in a 25-cycle generator will be greater than in a 60-cycle generator—due mainly to lower reactance and the resulting greater values of ampere turns—all 60-cycle ratings indicated by the limiting curve will have substantially equal forces developed on sudden short circuit. The stresses in the coil ends will be determined by these forces and by those factors determining the rigidity of the winding. Except possibly in the maximum size 1500-rev. per min., 25-cycle generator, with its long coil-end extension, there need be no material difference in the rigidity of the winding. Thus a 50,000-kv-a., 25-cycle, 1500-rev. per min. generator represents the most difficult design from the standpoint of short-circuit stresses. However, such a generator would not differ materially in short circuit stress conditions from 30,000-kv-a., two-pole generators that have been in successful operation for three years. It can be stated with confidence that the danger of winding failure due to sudden short circuit, with generators of the indicated limiting outputs, will be no greater than 20,000- and 30,000-kv-a. generators that have been placed in operation in large numbers during the past six years.

Another question of interest to those responsible for the operation of large generating units is the extent of damage to winding in case of internal short circuits caused by failure of insulation between turns of the same coil or failure of insulation from copper to ground. Experience with large units now in operation has shown that, in the event of a winding failure that results in the flow of abnormal power current, the chances are that the entire winding will be destroyed and that a hole of considerable size may be burned in the core laminations. Generating units are already of such size that a winding failure usually results in the loss of output from the unit for several months. The results of failures in still larger generators will be of the same degree and will be no more serious except, of course, in that loss in kv-a. output will be greater. In this connection, it is pertinent to point out that the fusing of metal and other local effects of an internal generator failure is a function of station capacity rather than of individual unit capacity. The volume of metal fused at the point of failure is determined largely by the impedance of the generating circuits feeding into the vault. Therefore, the only difference between a failure in one of two 30,000-kv-a. units and a failure in a single 60,000-kv-a. unit is in the impedance of the leads buses, and other connecting circuits between the two 30,000-kv-a. units. The two 30,000-kv-a. unit installation has the obvious advantages that protective reactance may be installed between the units, and the trouble is usually confined to half the station capacity.

The author has not intended to express an opinion as to the wisdom of installing very large single-shaft units. The only purpose has been to point out from the design standpoint the feasibility of certain ratings. Whether it is desirable or even wise to install very large units—above 50,000-kv-a.—will depend very largely on the growth and size of generating stations. When stations double in size—when stations of 300,000 kv-a. and 500,000 kv-a. become typical of American practise—there will undoubtedly be a demand of considerable volume for units of 50,000 kw., 75,000 kw., and 100,000 kw., and if single-shaft units are justified from the turbine standpoint, there is no question but that such generators can be conservatively designed and constructed.

To be presented at the 355th meeting of the American Institute of Electrical Engineers, New York, November 14, 1919

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PRESENT LIMITS OF SPEED AND POWER OF SINGLE-SHAFT STEAM TURBINES

BY J. F. JOHNSON

ABSTRACT OF PAPER

This paper will be restricted to a discussion of some of the factors which influence limits as applying particularly to turbines of the reaction type. With the employment of high vacua the limit of power will be determined largely by the area obtainable through the last stage.

Limiting factors include:

1. Chosen maximum values of steam speed through the blades in order to keep the leaving losses within permissible limits. For highest efficiency the steam speed should be about 25 per cent greater than the blade speed, but in the last stages it is sometimes made 100 per cent greater as a compromise between efficiency and cost. Similarly the outlet angle of the blades is increased from 20 deg. to 35 deg.
2. Physical characteristics of materials employed and chosen limits to which these may be safely stressed. By varying the form of rotor construction stresses in it may usually be kept within necessary limits up to the point at which limiting stresses in the blades or blade fastenings are reached. For any given rotative speed and blade angle the steam capacity is directly proportional to the stress at the base of the blades regardless of the diameter and blade height.
3. Capacity limits of manufacturing facilities, increased bracing and clearances necessary to insure requisite rigidity and reliability, and capacity loss due to outages for inspection and repair.

Fig. 6 shows maximum capacity at various speeds which are physically possible without exceeding present limits of stresses. It is valuable chiefly as showing the physical relation between speed and capacity with given limiting stress values.

THE recent rapid development of steam turbine-driven electric power-generating units of large capacity has prompted your Society to undertake a study of the present limits of speed and power for such units. This paper will be restricted to a discussion of some of the factors which determine or influence such limits as applying particularly to turbines of the reaction type.

With the employment of high vacua, such as is the present universal practise, the limit of power of a turbine operating at a given speed will be determined largely by the area obtainable through the last stage for the final expansion and passage of the steam prior to its entering the condenser. The significance of this will be apparent when attention is called to the fact that whereas a pound of steam, when entering the first stage, has a volume of less than 2½ cu. ft., when passing through the last stage it has a volume of approximately 395 cu. ft. when expanded to 28½ in. vacuum, and 585 cu. ft. when expanded to 29 in.; a ratio in the latter case of 1 to 234.

Consequently, in any discussion of limits of power, it will be necessary to assume conditions of pressure and superheat of the steam entering the turbine, the vacuum to which the steam is to be expanded in the blading, and the efficiency or rate of steam flow per unit of power. For these conditions 250 lb. gage pressure with 200 deg. fahr. superheat and 29-in. vacuum referred to a barometer of 30 in., and efficiencies as are commonly obtainable with them, will be used.

Limiting factors may be divided into three classes: First; Theoretical, including limiting steam velocities and effect on efficiency of velocity remaining in steam after leaving the last stage, and the area through the blades as affected by blade angle. Second; Physical, including methods of construction, materials, stresses, factor of safety against rupture, reliability factor, and limitations of transportation facilities. Third; Economic, including limits beyond which it may be physically possible, but economically inadvisable, to go, such as effect of size of structure or of character of materials employed on cost, and time required to make inspection and repairs.

THEORETICAL LIMITS

In this class there are but few limitations as affecting capacity at a given speed because with materials of infinite strength and rigidity available it would be possible to build units of infinite capacity; but for a given diameter and blade height the capacity will be limited by chosen maximum values of steam speed through the blades, in order to keep the leaving losses, or available energy in the steam discharged to the condenser, within permissible limits. Throughout the entire turbine, with the exception of the last few stages, steam speeds only about 25 per cent in excess of the corresponding blade speeds are employed in order to secure maximum efficiency. In the latter stages, however, the volumes become so great that a compromise between maximum theoretical efficiency and physical dimensions becomes advisable by increasing the steam speed sometimes to approximately 100 per cent in excess of the blade speed. The steam after being discharged from the last stage, therefore, still contains a small portion of available energy the recovery of which would involve disproportionate expense.

For example, if the pressure drop in the last stage is such as to render available for work thirty heat units which will produce an equivalent velocity of 1225 ft. per sec., and if the blade speed is such that the steam after leaving it still has a velocity of 600 ft. per sec., which is the equivalent of 7.2 B. t. u., this 7.2 B. t. u. will be totally lost, whereas probably 80 per cent of it, (or 6 B. t. u.), might be recovered were it practicable to use an additional stage of proper proportions. This would improve the total efficiency of the turbine approximately 1½ per cent. Higher blade speeds will tend to improve the efficiency by reducing leaving losses, but generally not as effectively as would larger blade areas with lower steam velocities and correspondingly increased number of stages.

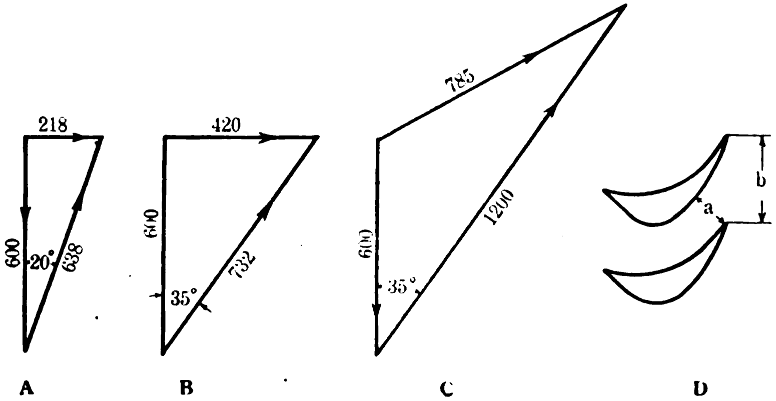

FIG. 1

Having fixed the height of a row of blades, the area of the steam space is dependent upon the angle formed between the center line of the row of blades and the outlet portion of the blade. The smaller this angle is the smaller will be the area and *vice versa.* On the other hand the smaller this angle the higher the efficiency because of the lesser absolute velocity left in the steam discharged to the condenser.

In Fig. 1A is shown a relation between steam speed and blade speed to give highest efficiency. The blade speed is 600 ft. per sec., steam speed 638 ft. per sec., blade angle 20 deg. and steam, speed after leaving blades, 218 ft. per sec. in direction at right angles to direction of rotation. Fig. 1B shows a similar condition giving maximum obtainable efficiency employing a 35 deg. blade angle and Fig. 1C a condition in which the steam speed is 100 per cent greater than the blade speed.

The leaving losses are, in Fig. 1A, 218 ft. per sec., Fig. 1B, 420 ft. per sec., and Fig. 1C, 785 ft. per sec., which is the equivalent of 0.95, 3.5, and 12.3 B. t. u. respectively.

The steam area is ordinarily expressed as a ratio of the perpendicular distance between blades, to the pitch of the blades, as a/b (see Fig. 1D). Highest actual efficiency is obtained by keeping this ratio between 0.25 and 0.3, and this is done in all stages except the last few in high vacuum machines where it is increased to a maximum of 0.5, the equivalent angle being about 35 deg. which includes proper allowance for blade thickness; this ratio having been determined upon as a proper compromise between cost of increased blade height and loss of efficiency due to increased terminal loss.

Some European manufacturers have employed ratios as large as 0.65 and 0.7.

PHYSICAL LIMITS

Chief among the physical factors limiting turbine capacity are the physical characteristics of the material employed and the chosen limits to which these materials may be safely stressed, bearing in mind that either uniformity of quality, or factor of safety sufficient to cover all possible variations, together with inaccuracies in calculation and irregularities of operation, must be provided for. While alloy steels possessing exceptionally high physical characteristics are procurable, their high qualities depend on relatively sensitive metallurgical processes which in the opinion of some engineers cannot as yet be carried out by regular workmen as a manufacturing process with a sufficient degree of reliability to justify their use, and that until this can be done, conservatism demands adherence to the lower strength, lesser sensitive materials. Such materials may, with suitable forms of construction, be safely stressed under the maximum test condition to within a few thousand pounds of their true elastic limits.

When the construction of the rotor is not limited to any one special form, the design may be varied so as to take full advantage of the low speeds in the high and intermediate stages, (where low speeds must be used in order to secure high efficiency), by employing a drum the thickness of which may be varied to keep the stresses within desired limits; while in low pressure stages where the stresses are highest, either disks carried on a shaft, or solid disks suitably held together, may be employed. With the solid disk construction the stresses may be kept within any reasonable limits up to speeds at which the design becomes too massive and expensive.

The steel regularly used by the Westinghouse company for turbine rotors conforms to the following characteristic specifications:

Test rings taken as close as possible to the point of maximum stress must show the following characteristics with standard two-in. specimens:

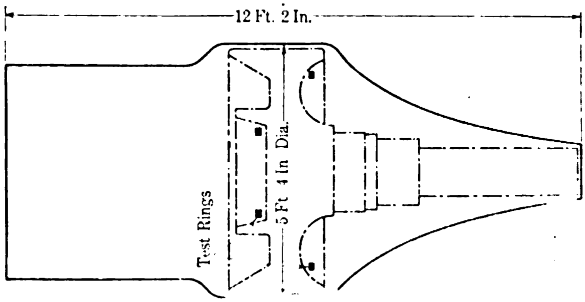

FIG. 2

Tensile strength 65,000 to 70,000 lb. per sq. in.

True elastic limit 22,000 to 25,000 lb. per sq. in.

Elongation 15 per cent to 18 per cent.

Reduction of area 20 per cent to 25 per cent.

The steel must be of best quality, having approximately 0.25 per cent carbon, 0.50 to 0.60 per cent manganese, 0.25 per cent silicon, and not over 0.025 per cent sulphur or of phosphorus.

The material is obtained ordinarily in the form of castings, though occasionally as forgings. The specifications in either case are the same. Especially in the larger sizes the forgings have been difficult to obtain, excessively expensive, and no more uniform or reliable in quality than the castings.

Fig. 2 shows the form of casting for a rotor end. It is cast vertically with the small end down, and after casting, is allowed to cool very slowly in the sand. After removal, the entire upper portion which constitutes the riser, is cut off and the casting then thoroughly annealed by being heated slowly and evenly to a temperature of about 1650 deg. fahr. and allowed to cool very slowly. It is then rough machined to within about ¼ in. of finished surface, after which it is put in a furnace and heated to about 1100 deg. fahr. and allowed to cool slowly to remove any possible internal stresses set up by reason of the metal removed in machining. It is then finish machined and given no further treatment of any kind.

The limit of stress to which this material is subjected is 20,000 lb. per sq. in. when operating at a speed 20 per cent in excess of the normal operating speed. The stress at normal speed is therefore $\frac{20,000}{(1.20)^2} = 13,900$ lb. This stress is 63 per cent of the minimum allowable true elastic limit, about 46 per cent of the yield point and 21½ per cent of the minimum ultimate strength. It is not generally appreciated that should the stress, by reason of defect or excessive overspeed, exceed the true elastic limit, no injury will result other than a slight permanent stretch, together with such blade damage as may result therefrom. In an extreme case of overspeed the rotor drum or solid disk will stretch, sufficiently to cause blading to rub to such an extent as to practically insure entirely destroying it, and thus prevent further overspeed, before the ultimate strength and elongation of the material is reached.

If the rotor design can be so modified as to always keep the stresses within necessary limits, then the stress at the base of the blades, or in blade fastenings, determines the maximum capacity obtainable with a given speed.

There exists two interesting relations between the stress at the base of blades, steam passage area through the blades, and rotative speed. *For any given rotative speed and blade angle, the steam capacity or steam area through the blades is directly proportional to the stress at the base of the blades, regardless of the diameter and blade height selected.* This stress can only be modified by unevenly varying the cross sectional area of the blades, such for example, as thickening the blade near the base. *Also for any given stress the area through the blades will vary inversely as the square of the speed, i. e.,* if at a speed of 1800 rev. per min. a given stress and area are obtained, then at 900 rev. per min. the area will be increased four times if the stress is kept constant.

These relations will be readily seen from the following formulas:

$$\text{Area through blades} = \pi \times M\,D \times H \times R.$$

$$\text{If } R \text{ constant} = \text{Constant} \times M\,D \times H$$

$$\text{And stress at base of blades} = \frac{W\,V^2}{G\,r}$$

$$= \text{for steel} \frac{0.284 \times H \times \left(\dfrac{\text{rev. per min.} \times M\,D}{229}\right)^2}{32.16 \times \dfrac{M\,D}{24}}$$

$$= \frac{0.284 \times 24 \times M\,D \times H \times (\text{rev. per min.})^2}{32.16 \times (229)^2}$$

If rev. per min. is constant = constant × $M\,D \times H$.

Where H = Blade height in inches.

$M\,D$ = Mean diameter of blades in inches.

R = Ratio of area through blades to total annular area occupied by blades.

0.284 = Weight of blade material in lb. per cu. in.

The area and stress are therefore each equal to a constant times the product of mean diameter and blade height, and when the stress is constant this product will vary inversely as the square of the rev. per min.

The ratio of blade height to rotor diameter is, therefore, not a factor in determining physical limit of capacity, but only in determining efficiency, cost, and to some extent, reliability of the turbine.

Blading used in impulse stages and in low pressure reaction stages in which stresses exceed 15,000 lb. per sq. in. at 20 per cent overspeed is made of a 5 per cent electric furnace nickel steel in which the carbon sulphur and phosphorus are kept very low. It is really a nickel iron having a very fine close structure.

Its physical and chemical characteristics are as follows:

Tensile strength	65,000 lb. per sq. in. minimum
True elastic limit	35,000 lb per sq. in. minimum
Elongation in 2 in.	30 per cent minimum
Reduction of area	60 per cent minimum

Carbon, not over	0.08 per cent
Silicon, not over	0.10 per cent
Phosphorus, not over	0.025 per cent
Sulphur, not over	0.04 per cent
Manganese	0.40 to 0.50 per cent
Nickel	4.5 to 5.5 per cent

This material is annealed by heating to 1425 deg. fahr. and cooled in open air after rolling into sections required for forming into various blade shapes, and is given no further heat treatment.

The maximum stress at 20 per cent overspeed to which this material is subjected is 25,000 lb. The corresponding stress at normal speed is, therefore, 17,350 lb., this being 49 per cent of the true elastic limit, and 26½ per cent of minimum ultimate strength.

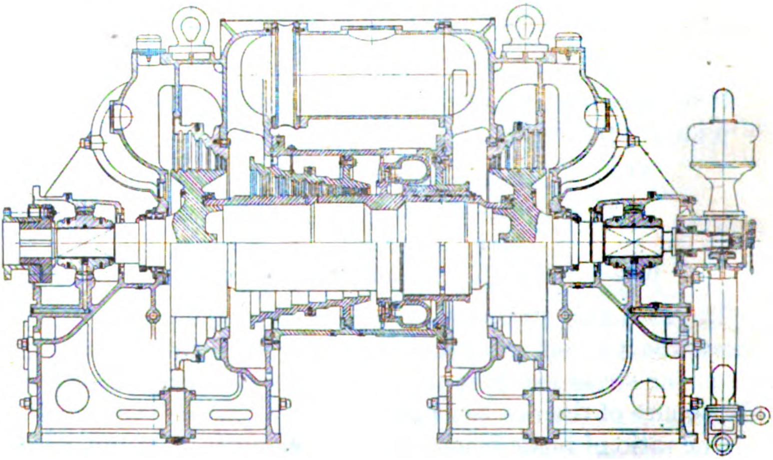

Fig. 5

For the lower stress reaction blading, a copper tin and phosphor bronze is employed, consisting of:

Copper	97 to 98 per cent
Tin	2 to 3 per cent
Phosphorus	0.03 to 0.07 per cent

Satisfactory methods of blade fastening involve no problems unless allowable stresses in the blades are very materially higher than those in the blade carrying element.

Fig. 3 shows a method used where the stress at the base of the blade does not exceed 17,500 lb., and Fig. 4 where stresses between 17,500 lb. and 25,000 lb. are involved. At 25,000 lb.

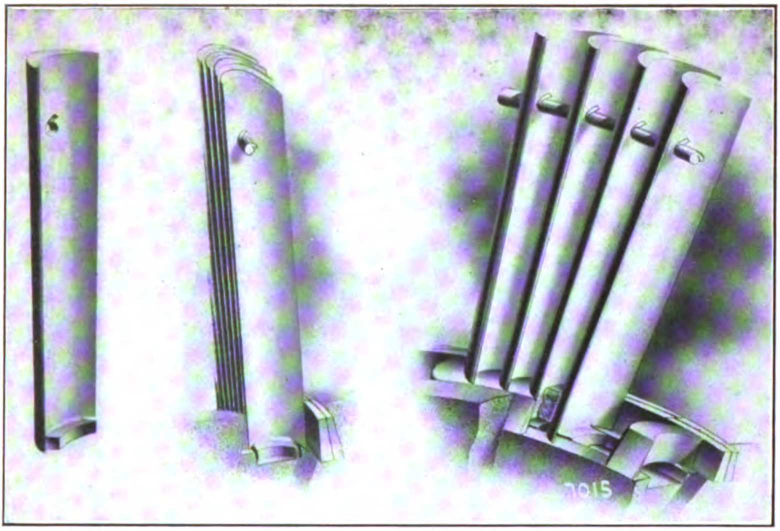

FIG. 3.

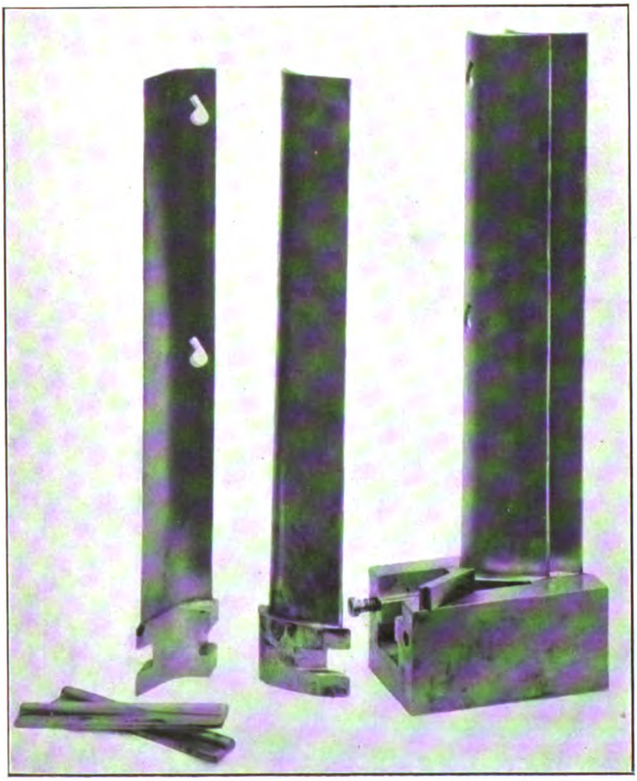

FIG. 4

[JOHNSON]

stress at the base of the blade the tensile stress in reduced section of base is 11,800 lb., and the shearing stress in the blade and blade carrying element is 10,000 lb. The compound side wedges are employed to insure an absolutely tight fit of the blade in the groove so as to protect the reduced section of the blade against any stresses other than direct tension.

Increased capacity without decrease of rotative speed or increase of stresses may be obtained by employing multiple low pressure stages. This well known and popular expedient possesses the merit of permitting high-vacuum turbines to be built at speeds and capacities up to approximately the present limits of generator construction, without exceeding moderate diameters blade lengths, and stresses.

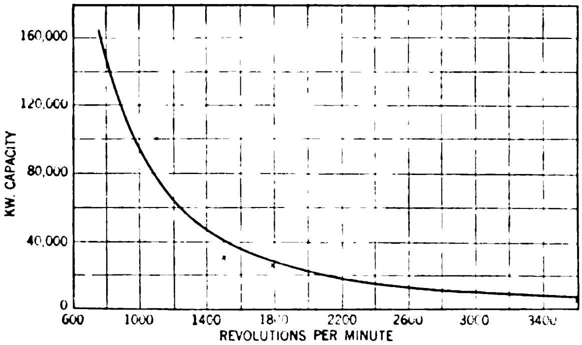

FIG. 6—LIMITS OF CAPACITY OF STEAM TURBINES WITH DOUBLE-FLOW LOW-PRESSURE STAGES

Having steel blades of uniform cross-section stressed to 25,000 lb. per sq. in. at base of blades at 20 per cent overspeed and maximum efficiency at 80 per cent of rating—250 lb. steam pressure—200 deg. superheat—29-in. vacuum referred to a 30-in. barometer—with steam velocity through blades of 1225 ft. per sec. at a volume of 585 cu. ft. per lb.

Fig. 5 shows a cross sectional view of a turbine typical of this type.

Fig. 6 is a curve showing approximate maximum capacities at various speeds which are physically possible, employing double flow construction without exceeding the limits of stresses previously given. For equal capacities employing single flow construction the stresses would have to be doubled. The points marked (x) at 3600, 1800 and 1500 rev. per min. represent capacities which have already been built. This curve must not be interpreted as indicating suggested practicable present or ultimate limiting capacities of turbines, but merely as showing a physical relation between speed and capacity with given limiting stress values and operating conditions.

An important limit of size and capacity now being approached is that imposed by transportation facilities. Stationary elements may be readily sectionalized as required and assembled after shipment. Ways may be devised also for partial dismantling of rotor elements, although diameter will be one of the limiting factors, and this cannot be reduced beyond the point of omission of blading. The low-pressure rotors of the 30,000-kw. Interborough Rapid Transit Company turbines were shipped with the last stage blade carrying elements removed.

While the physical dimensions and capacities of turbines are being constantly increased it is essential that the reliability factor be not decreased. The employment of special materials and higher stresses does not usually permit increased capacity or efficiency without a corresponding increase in weight and cost unless reliability be compromised.

If, having given a satisfactory reliable design of a given capacity employing low stresses, it is proposed to transform it by modification of design and substitution of higher stresses into a unit of larger capacity, greater blade lengths and probably greater blade weights, operating at higher speeds, and involving higher centrifugal forces will be necessary, in order to secure the required area. The rotor structure may possibly be shortened somewhat, but unless its total weight is increased nearly in proportion to the increase in stored energy in the individual blade; the unbalanced effect or disturbance caused by one or more blades breaking (which must be recognized as an inevitable occurrence in any turbine) will be greater, imposing higher stresses in the rotor shaft, bearings, and bearing supports; and a greater factor of strength will be required to withstand these stresses. The greater blade weight and higher speed will also require increasing the mass of the casing in order to prevent the blades from permanently injuring and possibly breaking through it if they should fail. The endurance factor of a turbine when operating under imperfect or abnormal conditions will be higher in proportion to the ratio of stator mass to rotor mass, and of rotor mass to blade mass. The incorporation in the design of a turbine of features which increase the endurance factor will appreciably increase its cost but will also (to a very much greater extent) increase its value to the user.

ECONOMIC LIMITS

In the study of economic limits of turbines of large capacity, consideration must be given to the fact that as yet such units are not required in sufficient quantity to warrant equipping and operating shops for their exclusive manufacture, and that they must, therefore, be produced by largely the same processes and equipment as are used for smaller sizes which are built in greater quantities.

As sizes becomes larger, a greater proportion of special equipment and processes becomes necessary, resulting in increased rates of cost unless accompanied by very material increase in quantity of production. Under present conditions this economic limit of capacity agrees closely with the physical limit of 1500 rev. per min. units.

In the larger low-speed structures the physical proportions become such that using ordinary steel and cast iron, to which we are limited by the metallurgical art, the distortions due to temperature changes and elastic properties of the materials are such that increased clearances and bracing have to be employed, in order to maintain equal reliability and rigidity to a degree which causes the cost per kilowatt for a given efficiency to increase with increasing capacity. Further development of the allied arts and increased demand for larger units will tend to reduce the influence of this limitation factor.

Another factor tending to limit capacity of single units is the generating capacity loss resulting from suspension of service for inspection or repairs. For example, if a 30,000-kw. unit must be kept out of service ten days for a certain inspection or repair, a 60,000-kw. unit would have to be kept out probably fourteen days for a similar purpose because of the greater time required to handle the larger structure. Therefore, if two 30,000-kw. units were used and each held out of service ten days, the outage loss would be only five-sevenths as great as if a single 60,000-kw. unit were kept out fourteen days.

In order to avoid the limitations or undesirable characteristics just referred to, a number of turbine units of capacities varying from 30,000 to 60,000 kw. have been built in which the turbines have been divided into two or three separate compounded elements, each driving its own generator, and each capable of operating alone on high pressure steam in emergencies.

It is believed that units of this type will continue to be employed for the larger capacities because of the advantages not obtainable in single cylinder types, which will justify their somewhat greater cost.

Presented at a joint meeting of the American Institute of Electrical Engineers, and the Institute of Radio Engineers, New York, October 1, 1919.

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(*Subject to final revision for the Transactions.*)

TELEPHONE REPEATERS

BY BANCROFT GHERARDI AND FRANK B. JEWETT

Abstract of Paper

In this paper the authors have endeavored to set forth briefly but clearly the history of the research and development work which has led up to the final production of successful telephone repeaters. The various forms of amplifiers which have been suggested are described and their possibilities and limitations pointed out. The essential properties of repeater networks together with the necessary line conditions for successful repeater operation are described and illustrated. Tandem operation of repeaters is discussed as is also the use of repeaters in four-wire circuits. Illustrations are given showing a few of the more important repeater installations now in regular commercial service in the United States.

Introduction

DURING the past ten years developments in the design and construction of telephone amplifiers, or telephone repeaters as they are more universally called, and in the art of their application to all forms of telephone circuits have progressed to such an extent as to justify the presentation to the American Institute of Electrical Engineers of a comprehensive paper which shall cover not only the earlier efforts but the present state of development.

As indicated below, the idea of one or more repeaters inserted in a line for the purpose of reinforcing from some local source of energy the weakened current from the sending station is older than the telephone itself. In telephony innumerable attempts by a large number of investigators have gone on continuously almost from the inception of the telephone in an effort to extend the range of telephonic speech through the utilization of energy applied to the telephone line at a point or points between the transmitting and receiving stations. While the net result of all this work is, of course, the state of the art as we now have it, a survey of the earlier developments in the light of present-day knowledge discloses in striking fashion the fact that, unknown to the investigators, the early attempts were destined not to succeed where success was measured by the development of a practical device which would give satisfactory results on a regular two-way telephone circuit.

We know now that the final successful development and application of the telephone repeater had to wait not only for the slow accumulation of comprehensive knowledge concerning all the factors which govern the successful transmission of speech electrically over wires and of the intricate relation of circuits and apparatus to produce desired results with the maze of frequencies involved in speech, but also on developments in physical science which were in themselves quite foreign to the specific realm of telephony. For these reasons the work of the earlier investigators, ingenious though it was, was for years foredoomed to failure by factors over which they had no control and of which, in many cases, they had no knowledge even. In the light of what we now know, much of this early work appears almost impossibly successful and attests to the ingenuity and resourcefulness of the men who conducted it.

Another thing which the final successful development and extensive application of the telephone repeater indicates with striking clarity is the fact that a complete solution of the problem was made possible only by the existence of a great unified engineering and research department, such as that maintained by the Bell System. The elements involved and the multiplicity of detail to be worked out and correlated were far beyond the limitations of any single individual or any limited organization. The best that mathematics, physics, chemistry, engineering, manufacturing and operation could supply were needed for the solution. Further, if the solution were to be obtained in a reasonable time it was essential that the efforts of the experts in all of these fields must be directed in a cooperative attack on the main problem. With the growth of fundamental research groups of highly trained scientists in the engineering department of the Bell System the means for attacking the elusive repeater problem in comprehensive fashion became available and progress toward success became certain and rapid. The loose ends of discrete and desultory researches were gathered in, past and present work scrutinized and the attack directed from a foundation of certain knowledge not theretofore available.

The wonderful success which has attended the work and which has started what bids fair to be a revolution in the entire scheme of telephonic transmission should be a source of gratification to American electrical engineers, to whom more than to any others have been due the other wonderful telephone developments of the past.

In discussing the earlier work on telephone repeaters and that which led up to the first successful device, the authors have not attempted even to enumerate the large number of investigators, much less to allocate credit among them. The names mentioned are those of the men who stand out most conspicuously and the fact that many of them are employees of the Bell System is not remarkable, since it was the largest single agency consistently at work on all problems concerning telephone development. In a complex art which has been vigorously worked for nearly fifty years, it is inevitable that great numbers of patents should have been taken out on all conceivable kinds of devices and systems. Many of these are inherently worthless, while others contain elements of value, although not in themselves disclosing complete workable arrangements. While, therefore, no single invention has solved the repeater problem in its entirety, it is interesting to note that all of the inventions which make possible the successful telephone repeater of today are the work of Americans.

No paper dealing with the development and successful application of telephone repeaters would be complete without mention of the fact that throughout all the later years, during which progress has been certain and rapid, the principal credit for the broad engineering and commercial results obtained is due to Colonel J. J. Carty, past President of this Institute and for many years Chief Engineer and now Vice President of the American Telephone and Telegraph Company. To Colonel Carty more than to any one else is due the credit of having brought about that coordination of all of the elements mentioned above which was vital to the ultimate success of the undertaking.

HISTORICAL

The foundation of the art of telephony by Alexander Graham Bell followed by almost fifty years that institution of the sister art of telegraphy which was based on the discoveries of Faraday, Ampere, Volta, and Henry. It was inevitable, therefore, that efforts to extend the range of telephonic communication should be influenced by earlier and successful efforts in telegraphic communication. As telegraphic operation was attempted between more widely separated stations it was found that the attenuated currents were insufficient to operate the recording mechanism. To obviate this limitation Morse introduced at the receiving station a local source of energy which supplied current to the recording mechanism but was controlled by the received signals through the medium of an electromagnetic relay.

In this invention was the principle necessary for an indefinite extension of the possible range of communication since the local source might supply current to another stretch of line. It is a curious bit of history that this application was not utilized for several years during which transmission over long distances was accomplished by manual instead of automatic repetition at the intermediate stations.

The delay in this natural development was due to the fact that the relay of Morse, although it was a repeater, was a one-way device since it was actuated only by currents arriving from one of the two telegraph stations on either side of it. It required the use of two such repeater elements and of a circuit arrangement to convert a one-way into a two-way repeater station. Of these circuit arrangements one of the earliest was that of Varley. During the next few years duplex repeaters received considerable attention from inventors. The differentiation, however, which seems so obvious to us today, between the repeater element and the circuit arrangement by which such elements may operate duplex, was infrequently if ever emphasized.

In the extension of the range of telephony by the use of repeaters the duplex feature was even more essential than in telegraphy. The problem was complicated not only by the inherited confusion between element and circuit but also by the greater importance of the third factor in such operation, namely, the lines on either side of the repeating station.

The necessity for distinguishing between these three factors of repeating element, repeater circuit, and lines was early recognized by the engineers of the Bell System. The exact and quantitative relationships between them have been adequately expressed for about a decade. In our discussion of the matter in hand we shall follow, therefore, the logical order which results from this differentiation and treat these factors separately in the above order. Before undertaking their more detailed exposition it may be well to vivify their individuality by the consideration of the concrete case illustrated in Figs. 1 to 5 inclusive.

A principle, which is familiarly known by its direct-current application in the Wheatstone bridge, has proved most fertile in the formation of duplex circuits. Thus in Fig. 1 we have an early method of duplex telegraphy, which is obviously reducible to the simple bridge circuit of Fig. 2. If *a* and *b* are equal then, provided also *R* is equal to *X*, the battery *B* will cause no difference of potential between *m* and *n* and hence no current through the galvanometer in the case of Fig. 2 and no resultant magnetism in the sounder of Fig. 1.

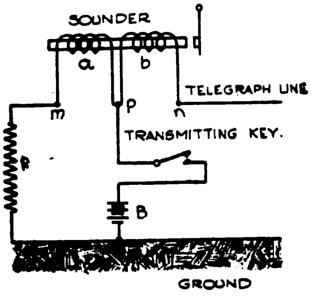


FIG. 1

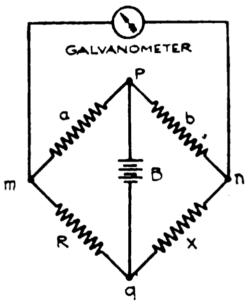


FIG. 2.

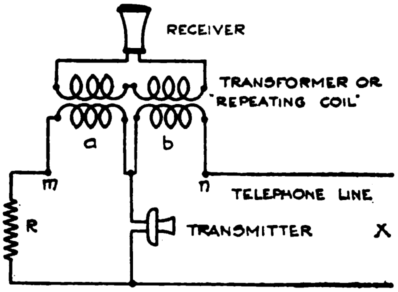


FIG. 3.

The same principle is applicable to the duplex operation of a telephone line as is seen in Fig. 3, where the sounder and the key of Fig. 1 are replaced respectively, by a receiver and a transmitter. If the resistance *R* is not equal to *X*, the impedance of the telephone line, then, the duplex set is not entirely "anti-side tone" since the operation of the transmitter causes some current in the receiver. The amount of current through the receiver and hence the motion of its diaphragm depends both upon the current from the transmitter and upon the amount of unbalance in the bridge which is occasioned by the inequality of *R* and *X*.

If we dispose the transmitter and the receiver as in Fig. 4, allowing any sound from the latter to actuate the transmitter, then we may obtain what is termed a "howling set". The mere jarring of the carbon button due to bringing the instruments into juxtaposition will result in a current from the transmitter and hence, if *R* and *X* are not equal, in some current in the receiver. The consequent motion of the receiver diaphragm causes a new disturbance of the carbon of the transmitter and this in turn causes a new impulse of current through the receiver itself. If the combination of receiver and transmitter is sufficiently sensitive this sequence of events may perpetuate itself and result in a steady tone, the frequency of which is determined by the electrical and mechanical characteristics of the system. The energy for such steady vibrations of the diaphragm is, of course, obtained from the battery associated with the transmitter. (For purposes of simplicity the battery is not shown in Figs. 3 and 4. It may be either a battery associated locally with the transmitter or one at the distant central office.)

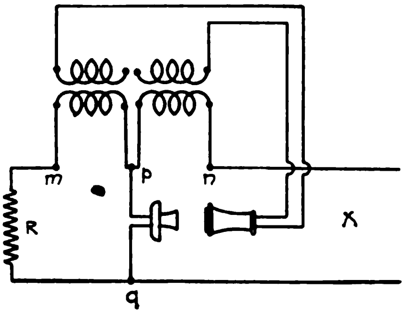


FIG. 4

From this illustration of the "howling set" the importance of line balance may be seen, for the combination of receiver and transmitter constitutes a repeater element. The element may more conveniently be symbolized as in Fig. 5 where the resistance, *R* of Fig. 4, has been replaced by a telephone line. In this last form of the bridge we may recognize the three factors mentioned above. The repeating element has input terminals *1, 2* and output terminals *3, 4*. It is associated with the lines on either side by the bridge circuit *m n q q* in such a manner as to repeat telephone conversations in either direction. Thus voice currents originating at a station on the east line are impressed on the terminals *1, 2* of the element through the action of the transformer. The resulting output from terminals *3, 4* is then transmitted equally to the east, where it is received as side tone by the speaker, and to the west, where it is usefully received by the distant auditor. Further details of this operation will be considered later. We may, however, note that if the unbalance between the lines east and west exceeds a certain magnitude, which depends upon the sensitiveness of the element, then the operation is that of the howling set. Under these conditions the repeater is said to "sing," for it will transmit in both directions a strong steady tone which renders telephonic communication impossible.

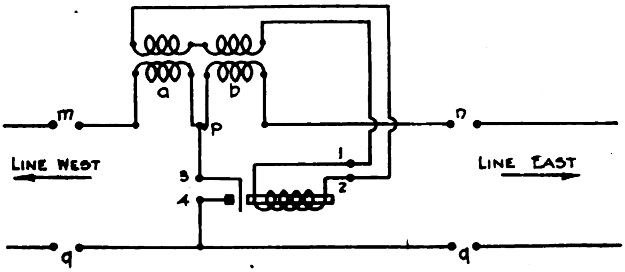


FIG. 5.

The difficulty introduced by this possibility of singing was not serious in the early days of the development of telephone repeaters and only became so with the invention of more sensitive elements. In fact in the very early days the difficulty was to obtain an element of sufficient sensitiveness. What sort of conditions must be met may be illustrated by the fact that the current at the transmitting terminal of a long line is only a matter of 2 or 3 milliamperes. In transmission over the line the current is constantly attenuated so that at the receiving terminal it may be only 3 or 4 hundredths of its original magnitude. Such small currents required greater precision of design than was appreciated by many of the early inventors, although as early as 1888 one of the Bell engineers, E. H. Lyons, had constructed a repeater which would amplify such small currents.

THE REPEATER ELEMENT

Before considering further these early designs we may well list the operating requirements for a successful repeater element. In so doing we shall not be concerned with the physical principles upon which the device operates. To all present intents and purposes we are concerned only with pairs of terminals *1, 2* and *3, 4* of an enclosed and unknown electrical network as illustrated in Fig. 6. If we subject such a hidden element to electrical measurement with alternating current we may obtain, for each frequency which we use, several characteristic ratios. Thus, from the ratio of the voltage impressed upon terminals *1, 2* to the resulting current we obtain the impedance of that circuit and similarly for the circuit of terminals *3, 4*.

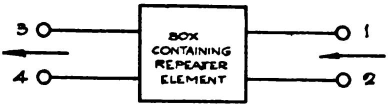


FIG. 6.

We obtain also a mutual impedance by taking the ratio of the voltage produced in the circuit *3, 4* to the current in the circuit *1, 2*. Similarly, there may be measured the mutual impedance in the opposite direction. In case one only of the mutual impedances is zero, that is, that no voltage is produced on one side when a current is flowing in the other, we speak of the device as having a "unilateral mutual impedance." Of the repeaters which we have found best adapted to telephony all are of this unilateral type. The requirements which must be met are identical whether the device is bilateral or unilateral but they may be more conveniently stated in terms of the unilateral type, of which the receiver-transmitter (or mechanical form) shown in Figs. 4 and 5 is a simple illustration. These requirements are:

1. The unilateral mutual impedance must be independent of the amplitude of the impressed current, within the range required for telephone transmission. In other words, there must be a linear relation between the output voltage and the input

current of the repeater, in which case the output is directly proportional to the input. If this condition is not met there will appear in the output one or more harmonics of the impressed alternating voltage.

1a. The input and output impedances of the element must be similarly independent of the impressed voltage or else distortion will occur.

2. The unilateral mutual impedance must be independent of the frequency of the impressed voltage within the range required for the transmission of the human voice. If this condition is not met the various overtones in such a complex sinusoidal current as is initiated by a voice will not be faithfully reproduced in their proper proportions.

2a. The input impedance of the element should be independent of the frequency of the impressed voltage or else it should be the same function of the frequency as is the impedance of the telephone line to which it is to be connected. If this condition is not met a distortion, destructive of good quality, may be introduced. In this case the voltage actuating the repeater is not that which the telephone line would impress upon another similar line but is greater or less by a factor which depends upon the frequency. It is not sufficient that the element repeat accurately its input but it is also requisite that its input circuit receive from the telephone line without distortion.

2b. The output impedance of the element should be similarly independent of the frequency or else properly related to the impedance of a telephone line so that the line may receive without distortion the output of the repeater.

3. The element must give amplification; that is, ignoring the energy sources which may be associated with or be parts of the element, the efficiency as measured by the ratio of output and input energies of telephone currents must be greater than unity. For example in the case of the mechanical element, which was pictured above, the energy is supplied by the battery associated with the carbon button. We are concerned at present only with its efficiency for transferring telephone variations from terminals *1*, *2* to terminals *3*, *4*. How much greater than 100 per cent this efficiency must be will depend, obviously, upon costs and other engineering factors. A repeating element adaptable to our telephone plant may well be expected to give an energy amplification such that telephone currents, which

have been attenuated by about twenty miles of standard cable, will be restored to their original values by its action. In telephone parlance "the element should give a gain of about twenty miles." Since by transmission through twenty miles of standard cable both the current and voltage would be attenuated to about one-eighth, the energy delivered to the repeater circuit would be only one sixty-fourth of the original energy. Of this only one-half reaches the receiving element for the rest is dissipated in the bridge. Hence there must be supplied to the line on the output side of the repeater circuit 128 times as much energy as is received. A glance at the circuit of Fig. 5 shows, however, that the output of the repeater itself is equally supplied to the outgoing and the incoming lines. The element must be capable, therefore, of supplying 256 times as much energy as it receives. In other words, the element should have a telephone efficiency of about twenty-six thousand per cent.

4. The sources of energy associated with the element, and by virtue of which amplification is possible, must have voltages which may safely and conveniently be utilized in the telephone plant. For example, a repeater whose source of energy had a voltage of greater than 250 would be unsatisfactory in a plant which normally employs voltages not greatly exceeding 100.

5. The element must be either insensitive to external electrical disturbances or easily shielded from them so that cross-talk from neighboring telephone circuits or apparatus may not actuate it.

5a. Conversely, the element must not be such as to cross-talk into adjacent circuits or apparatus.

6. The element must be constant in behavior, reliable and of fair life, and not such as to require frequent attention or laboratory conditions of operation. In other words the element must meet the conditions as to reliability of service which apply to other portions of the telephone plant.

7. In size, first cost, cost of energy and of maintenance, the element must conform to the economic conditions of an established plant.

Recognition of these conditions has guided our search for new elements during the past fruitful decade. Even before that time these requirements were recognized although they were not completely formulated. It is surprising how many independent inventors approached us during this time with devices formed by coils and magnets but involving no source of energy, or at least utilizing none, and hence patently incapable of producing amplification. Inherently such devices were static transformers, on the low voltage side of which there might be a greater current but obviously not a greater power than there was expended as input on the high voltage side. In some instances such devices were said to be intended for frequent use along a telephone line at fairly regular intervals. Such effect in improving telephone transmission as they might have would then be explainable by their function as inductances in the line; in other words, by the loading of the line. They thus offered imperfect substitutes for Dr. Pupin's method of loading.

Most of the earlier attempts at the design of telephone repeaters followed the recognized lines of telegraph practice or of electrical power engineering. The life of the telephone, however, has been almost contemporaneous with that of the newer physics which deals with discharges through rarefied gases and which has led to the discovery of the electron and of steady electron streams in vacua. General knowledge of the electronic structure of matter has grown by leaps and bounds in the last few years and coincident with this growth has been our practical development of electronic repeaters.

For purposes of classification, therefore, we may divide repeating elements into three groups depending upon whether their moving parts consist of (a) molecular ions, (b) electrons, or (c) molecular aggregates, that is, ponderable matter in the ordinary sense. The first group we might call "gaseous", the second "electronic," and the third, "electrodynamic." We may also classify according to the means by which the moving parts are actuated, as (a) electromagnetic if the operation is dependent upon a magnetic field which is altered by the received current, and (b) electrostatic if operation is dependent upon an electrical field which is established or altered by the received current.

Electrostatic devices involving moving members of mechanical size are too insensitive to serve as telephone repeaters. In the case of gaseous or electronic devices such a method of control is, however, entirely practicable and, indeed, for electronic systems marvelously effective. Our system of classification may, therefore, be simplified by the omission of one class of mechanical devices. It must, on the other hand, be further complicated by the introduction under gaseous repeaters of a type of device which has no cognate in the other two classes. Such devices are conductors which depend upon the passage of current through themselves to alter their own characteristics. Something of this behavior is familar to all engineers who have worked with carbon arcs and remember their instability. For our purpose we may designate this type of repeater as a "negative resistance device" and postpone the justification of the terminology to later discussion.

The classification of repeater elements in the order in which they will be discussed is, then, as follows:

I. Electrodynamic repeaters
    A. Receiver transmitter type
    B. Generator type
        1. Direct current generator
        2. Alternating current generator
        3. Asynchronous generator
II. Electronic Repeaters
    A. Electrostatic
    B. Electromagnetic
III. Gaseous Repeaters
    A. Electrostatic
    B. Electromagnetic
    C. Negative Resistance

I–A. The form of telephone repeater which most naturally suggested itself to the early engineers is the combination of a receiver and a microphone essentially in the manner depicted in connection with our earlier discussion of the problem presented to telephone engineers by the necessity of increasing the range of telephonic communication. In the early years of telephony, no other means seemed available and prior to 1903 many unsuccessful attempts were made along this line. The parent Bell organization devoted the efforts of a large number of its best men to this problem, which was also a favorite with inventors outside of its organization. In the minds of the general scientific world further interest had been stimulated by the reported offer of a capitalist to pay one million dollars for a successful invention.

The solution was finally reached by one of the Bell engineers, H. E. Shreeve, who was assigned to the problem in 1903 after an earlier experience in the design of microphones and other telephone devices. Previous inventors had combined receivers and transmitters without recognizing that the normal functions of their diaphragms were those of sound collecting or emitting members and Shreeve omitted these unnecessary features.

Another difficulty in earlier designs had been the "packing" of the carbon of the microphone and one of his first studies had to do with its cause and elimination. He found it to be due to expansion which was occasioned by the heat liberated in the carbon chamber. In his first successful laboratory model a stretched steel strip was used as a connecting link between the receiver and the microphone and the microphone was designed so that the expansion of its parts under the influence of heat did not subject the granular carbon between the electrodes to increased pressure.

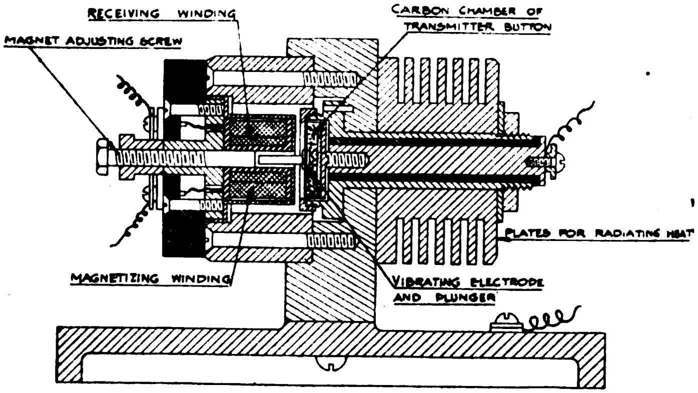

RECEIVING WINDING
MAGNET ADJUSTING SCREW
CARBON CHAMBER OF TRANSMITTER BUTTON
PLATES FOR RADIATING HEAT
MAGNETIZING WINDING
VIBRATING ELECTRODE AND PLUNGER

FIG. 7

With this form was obtained our first successful test of repeater operation over a telephone line. The device was tried in 1904 on a circuit between Amesbury, Massachusetts, and Boston and resulted in a greater intelligibility in the transmission of long lists of unrelated words than could be obtained over the circuit without the repeater.

The next step was to obtain more perfect quality reproduction and this was secured by making lighter moving parts and increasing the natural frequency of the moving system. The next model, shown in Fig. 7, was commercially operated on a circuit between New York and Chicago, from August 1904 to February, 1905. In this model the packing of the transmitter element was obviated by the thermostatic action of the vibrating disk, and the natural period of the moving parts was such as to emphasize the important frequencies of the voice. The element was associated with the line by a simple bridge circuit which had been patented by Edison in 1883. The transmission between New York and Chicago was found to be greatly improved.

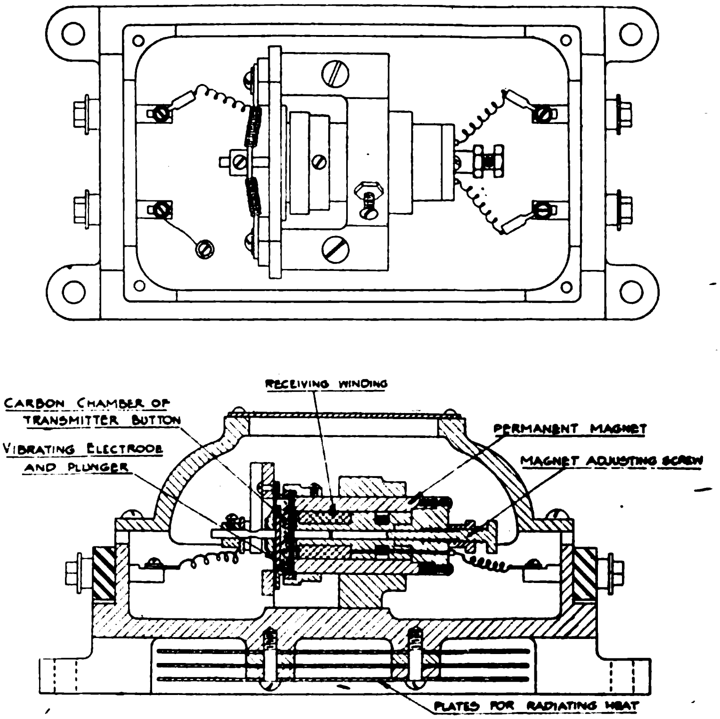

RECEIVING WINDING
CARBON CHAMBER OF TRANSMITTER BUTTON
VIBRATING ELECTRODE AND PLUNGER
PERMANENT MAGNET
MAGNET ADJUSTING SCREW
PLATES FOR RADIATING HEAT

FIG 8

In this installation an additional feature was incorporated to prevent amplification of the so-called "Morse thump," which occurs when a repeatered line is composited and carries superimposed telegraph signals. A repeating coil of low mutual inductance was inserted between the line and the receiving element. This coil was inefficient for currents of low frequency but was relatively efficient for those of voice frequency.

In spite of the success which was obtained with this first repeater installation, the problem was far from being solved. In fact, when an attempt was made to reproduce the model, it was found extremely difficult to obtain vibrating electrodes, which had the necessary thermostatic action in addition to other necessary characteristics. An attempt was, therefore, made to regulate the sensitiveness of the microphone by more positive means and the next model, Fig. 8, had the feature of a thermostat in the form of a zinc strip. This zinc strip was heated by a coil, which was in series with the microphone, and whenever the current through the microphone increased as the result of incipient packing it served to withdraw the rear electrode.

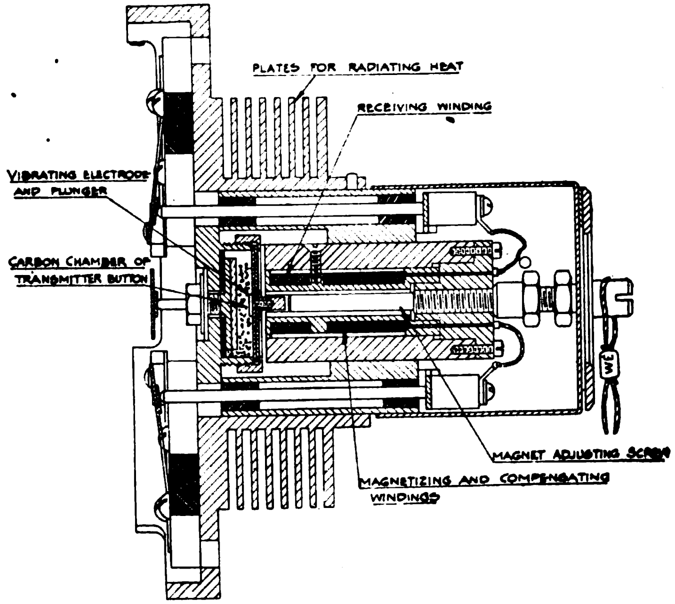

PLATES FOR RADIATING HEAT
RECEIVING WINDING
VIBRATING ELECTRODE AND PLUNGER
CARBON CHAMBER OF TRANSMITTER BUTTON
MAGNET ADJUSTING SCREW
MAGNETIZING AND COMPENSATING WINDINGS

FIG. 9

This repeater, known as No. I-A, was reasonably satisfactory in service until the requirements became more exacting, particularly in the matter of tandem operation with the attendant requirements of improved quality reproduction. An intensive study was therefore undertaken, with the result that the natural frequency of the vibrating system was raised still higher, the weight of the moving parts was still further reduced and a still more sensitive form of regulator adopted.

Without going into two much detail in regard to intermediate steps which were made between the 1-A repeater and the so-called 3-A type, which is the present standard for instruments of this type, it will be sufficient to describe the features of this latest model and to point out the inherent limitations of this class of repeater.

The 3-A repeater, Fig. 9, is of the so-called "cartridge" type and consists of two main parts, the cartridge and the socket. The cartridge contains all of the working parts which are liable to become defective in service and may readily be removed from circuit for the purpose of replacement. It is held in place in the socket by a bayonet catch, and electrical connections are made to its contact posts by springs in the socket. The regulating means which serve to maintain the sensitiveness of the microphone between extremely narrow limits consists of an electro-magnet with differential windings. The initial magnetic field of the receiving element is the resultant field produced by a winding in series with the microphone and an opposing winding in shunt with the microphone. If the steady resistance of the microphone increases, the series winding takes less current and the shunt winding more, or vice versa. These magnetic changes alter the pull on the flexible disk electrode and thus serve to regulate the pressure on the granular carbon.

An inherent defect in this type of instrument is the fact that the sensitiveness falls off rapidly when the input energy is below a certain minimum. At the present time no completely satisfactory explanation for this phenomenon has been advanced. A defect of this character is obviously serious in the operating plant where circuit conditions and volumes of energy at any given point in a circuit fluctuate widely from time to time. Thus at one moment the repeater in a given circuit may be handling the energy from two persons speaking loudly, using telephones very near the terminals of the circuit, while at the next moment it may be called upon to function with the energy which it receives from telephones connected to long circuits, which in turn connect to the circuit with which it is associated. If the persons using the telephones in this latter case have weak voices, if they do not use the telephones properly by talking directly into the transmitter, or if the apparatus

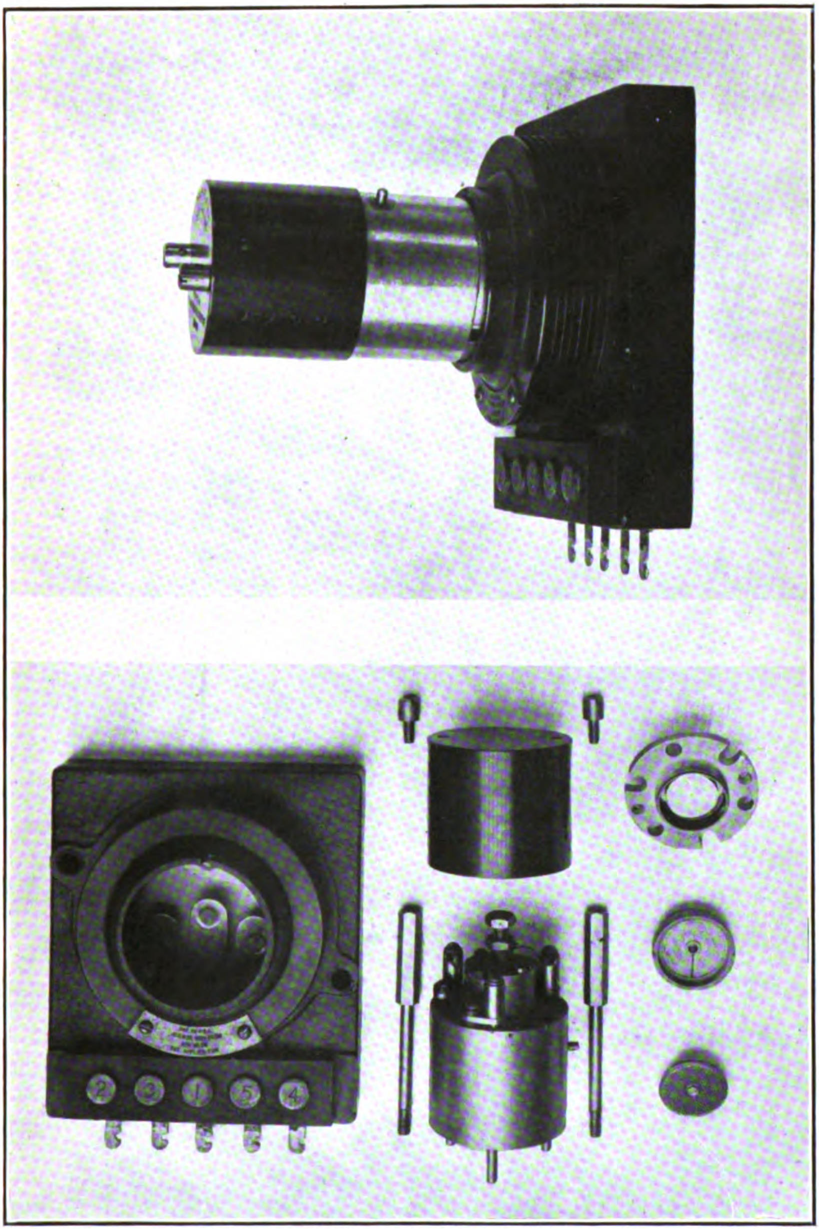


FIG. 9—MECHANICAL TYPE TELEPHONE REPEATER ELEMENT, SHOWING SOCKET, CARTRIDGE AND PRINCIPAL PARTS

[GHERARDI AND JEWETT]

or lines themselves are inefficient, it is clear that the energy at the repeater terminals may be many times less than that in the previous case. Further under those conditions maximum amplification is the more to be desired so that a repeater element whose performance fluctuates with the amount of energy which it receives and particularly one whose performance is worse when operating with the smallest energy is subject to a handicap when it comes to applying it generally in the telephone plant.

The Shreeve type of mechanical repeater is nevertheless distinctly serviceable and many units are in commercial service. The amplication is not, however, sufficiently independent either of the amplitude or of the frequency of the input to make them adaptable with best results to use in tandem, although they have been used to advantage on telephone lines the length of which did not require more than three repeater stations.

I-B. The application of the principles involved in direct- and alternating-current generators to the solution of the telephone repeater problem received the attention of some of the best minds in the art during the decade following 1900. During this time the problem was attacked both theoretically and in experimental design by H. S. Warren, M. I. Pupin, and others. The practice of power engineers suggested two typical methods.

(1) A generator of which the armature should constitute the output circuit of the element and the field winding the input circuit. Variations in the field current will result in corresponding variations of the armature voltage of such a machine. In order, however, that there should not be present in the armature voltage variations due to commutation, which would result in extraneous noise in the telephone, it is necessary that such a machine have a high frequency of commutation. If this frequency is well above that of the highest frequency which is essential to the faithful reproduction of the human voice, the noise currents due to commutation may be choked out by inductance or filtered out by a periodic structure like an artificial loaded line. When it is said that frequencies of 2500 cycles per second are required for good quality of telephone speech it is evident that for any practical design of armature and commutation the peripheral speed must approach the allowable mechanical limit.

Various unipolar designs were therefore considered in which no commutation is required. The principle involved may be seen by considering Fig. 10 which shows a form suggested in 1905 by G. A. Campbell. The field coil *M* is solenoidal and carries fixed disks, *w'*, which serve both as a magnetic core and as collectors for the radial e. m. f's. induced in similar disks, *w*, attached to the rotating shaft. In machines of this character where the field current is only of telephonic magnitude the flux is very small and the e. m. f. which may be obtained at any mechanically allowable speed of rotation is much below that requisite for a successful telephone repeater. In addition the eddy current and hysteresis losses are relatively high because of the frequencies involved and the efficiency is correspondingly low. The input impedance, being that of an electromagnet, is not independent of the frequency, as is desired, but instead is such as to discriminate against the higher frequencies of the voice wave.

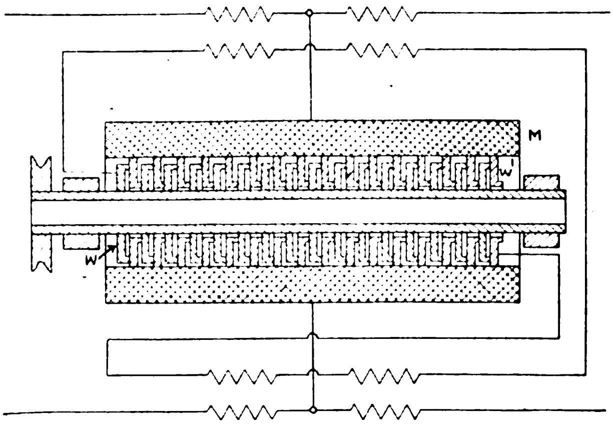


FIG 10

Even if it were possible to build and operate such high-speed generators as repeaters of feeble currents, the type is deficient in so many of the characteristics required of a successful commercial repeater that the extent of its use is questionable. Now that simpler and practically perfect repeaters are available, it is doubtful whether the limits of physical possibility in this type of apparatus will ever be worked out.

(2) The practical difficulties of eddy current and hysteresis

losses, of limiting speeds and of small input, were also effective in preventing the development of a successful repeater along the lines previously followed in the power engineering of alternating currents.

(3) In 1900, Joseph Lyons disclosed to us his invention, a telephone repeater upon the principle developed and patented in power engineering by Hutin and Leblanc. The principle is perhaps better known as that of the asynchronous generator, which is an induction motor driven above synchronism by a local source of mechanical energy. The conditions under which such a device may serve to supply energy to a transmission line, across which it is connected, are well known to electrical engineers. It was Lyons' idea that the stator should

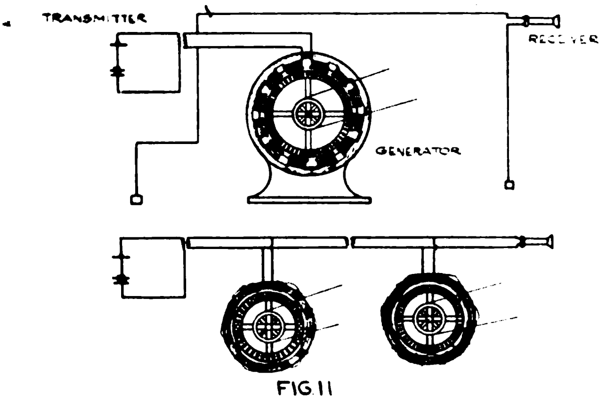


FIG. 11

be bridged across a telephone line and, through the interaction of the received current with that induced in the short circuited rotor, should supply to the line additional energy of the same wave form as it received. Schematically the circuit is as shown in Fig. 11.

In order, however, to supply energy at any telephone frequency the speed of the rotor must be at least as large as the quotient of the given frequency and the number of pairs of poles in the stator. Thus in the case of a 12-pole stator a frequency of 2400 cycles per second would require a speed of 400 revolutions per second. Not only are the speed requirements too high for practical operation but the machine would also fail to meet the second requirement for a repeater. The amplification for each frequency would depend upon the negative slip at that frequency and thus the lower frequencies of the voice current would receive more amplification than the higher ones. It was at one time suggested by Dr. Pupin that such distortion might be avoided by using several such asynchronous generators connected at different points of the line and each designed to amplify but a band of frequencies. Even had it been found possible to devise efficient machines to amplify the different groups of frequencies, it is doubtful if the arrangement would ever have proven satisfactory in an operating telephone plant, since at no point along the line between the first and last generator would the current have represented normal speech. This characteristic of the system would, of course, be a serious handicap to proper operation, since it would be almost impossible to tell whether the line were in trouble or not.

That the mechanical limitations of speed, clearance, thickness of lamination, and the other factors familiar to designers of dynamo equipment should have prevented the development of such a generator is understandable when the telephone requirements are stated in terms of power engineering. What was required was a generator which could operate on about one-half of a milliampere of field current. To give an energy amplification of 256 times, its field losses must be less than one per cent of the output. The value of one-half of a milliampere is the effective value of a complex wave form, all the sinusoidal components of which must appear in the output with equal amplification.

II. Electronic repeaters are those in which the moving parts are discrete electrons whose motions are unimpeded by molecular matter. Such devices, therefore, require a vacuum sufficiently high that the motions may be characteristic of free electrons. There must also be a means of supplying free electrons, that is of dislodging them from molecular matter of which they form constituents. The satisfactory method of accomplishing this is to "boil them out" of a piece of metal or metal oxide. Our present electronic repeaters are therefore "thermionic" devices.

The history of thermionics may be said to date from the publication in 1902–1903 of papers by O. W. Richardson in which he advanced a theory of the thermionic emission of electrons, which in all its essentials was accepted by the great majority of the scientific world and may now be regarded as definitely established. According to this theory (which is also a theory of metallic conduction) metals and conductors of electricity contain within their bounding surfaces immense numbers of free electrons which behave like the molecules of a perfect gas. When a metal is heated the kinetic energy of the electrons is increased and the number escaping across the boundary surfaces is likewise increased.

J. J. Thompson outlined the theory in his treatise on conduction of electricity through gases as follows:

"The emission of corpuscles from incandescent metals and carbon is readily explained by the view—for which we find confirmation in many other phenomena—that corpuscles are disseminated through metals and carbon not merely when these are incandescent, but at all temperatures, the corpuscles being so small are able to move freely through the metal and they may thus be supposed to behave like a perfect gas contained in a volume equal to that of the metal. The corpuscles are attracted by the metal so that to enable them to escape into the space surrounding it they must have sufficient kinetic energy to carry them through the layer at its surface where its attraction of the corpuscle is appreciable. If the average kinetic energy of a corpuscle, like that of the molecule of a gas is proportional to the absolute temperature, then, as the temperature increases more and more of the corpuscles will be able to escape from the metal into the air outside."

In 1904 Wehnelt discovered that the thermionic emission from conductors coated with certain oxides was enormously greater than that of pure metals. Since that date the study of thermionic emission has proceeded most rapidly and the practical applications of the phenomena have more than kept pace during the last eight years.

Phenomena due to thermionic emission had, of course, been observed for years before a satisfactory theory was advanced. The first of these instances was the discovery by Edison in 1884 of an effect which is now known by his name. He found that if a metallic plate is introduced into the bulb of an incandescent lamp and if the plate is connected to the positive terminal of the filament then a current flows between the plate and the filament as may be observed by a galvanometer inserted as shown in Fig. 12. This conductivity of the space between the plate and filament is unilateral, for if the plate is connected to the other terminal of the battery no current flows. The explanation of the phenomenon resulted from work of Fleming in 1896 and J. J. Thomson in 1899 along lines earlier pursued by Elster and Geitel. Fleming studied the operation of a two-member vacuum tube device having a heated filament and cold plate, and Thomson demonstrated that the mechanism of current conduction between the filament and plate resulted from the emission of negative electrons from the filament.

Through such a tube a current may flow, since electrons may pass and will so do provided the plate is positive with respect to the filament and hence such as to attract the electrons emitted by the latter. The idea of using such a two-element device as a rectifier and hence detector of wireless waves was applied independently in 1905 by Wehnelt and by Fleming.

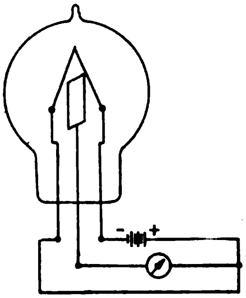


FIG. 12

For the next few years practical progress with thermionic devices was in the hands of the radio-engineers. In his American Institute of Electrical Engineers' paper of 1906 DeForest showed that the discharge between the hot cathode and the plate can be controlled by additional electrodes. In a patent issued the following year he shows inside the bulb such a controlling electrode to which he had given the form of a grid. With his discovery of a means for controlling the electron stream was born the most sensitive of repeating elements. Years of careful technical development were required, however, before the original idea had been perfected to the point where it met fully all the rigid requirements of application in a commercial telephone plant.

To understand the development which was required to adapt the first successful form of audion designed for radio-telegraph receiving to this use, we shall first consider in some detail the structure and physical principles of the device.

The "audion" consists of an evacuated vessel containing three electrodes, from one of which a thermionic emission of electrons is obtainable. Fig. 13 shows the characteristic structure. The filament is heated by the passage of a current as shown diagrammatically in Fig. 14. The other two electrodes are a plate and a grid. If a battery is connected to the filament and plate as in Fig. 14, so as to make the latter positive with respect to the former, then a current will flow in the circuit so formed. The electrons emitted at the filament are drawn across the intervening vacuum by the electrical field which the battery, *B*, in the plate circuit establishes. If an e. m. f. is now applied between the grid and the filament as by the source marked *V* in the figure, the field between plate and filament is altered and the current in the plate circuit is correspondingly altered. If the grid is made positive with respect to the filament more electrons are urged across the space between grid and filament. While some of this increase strikes the grid, and thus results in a current in that circuit, by far the greater number continue through the meshes of the grid to the plate. The result is an increased current in the plate circuit. Conversely, if the grid is made negative there results a decrease in the plate current. In this case, however, no current flows in the grid circuit because electrons can be drawn to an electrode only if it is positive with respect to the source of the electrons.

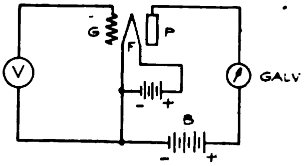


Fig. 14

The characteristic relation between the grid voltage, *V* and the plate current I_B, is that of Fig. 15. If the plate voltage is altered the form of the curve is not altered but the magnitude of the current is changed as illustrated in Fig. 16 which shows a family of such characteristics. It is evident from this figure that the number of negative volts which must be applied to the grid in order to reduce the plate current to zero is always the same fraction of the volts applied in the plate circuit.

Hence it appears that the current in the plate circuit may be altered either by altering the voltage there applied or by a much smaller alteration of the voltage applied to the grid circuit. The device thus gives a voltage amplification.

As long as the grid is kept negative no current can flow in that circuit and any alterations in its voltage are unaccompanied by any current variation and hence are entirely wattless. Such variations are accompanied by current variations in the plate circuit and result in an energy expenditure in that circuit. The telephone efficiency is thus seen to be practically infinite since an energy output may be obtained by a wattless variation of the input voltage.

To understand why the characteristic curve of Fig. 15 flattens out as the grid is made more positive we need only to remember that in the passage of a current through the plate-filament circuit two physical phenomena are involved. The first of these is the thermionic emission of electrons at the filament and the second is their enforced and directed transit between filament and plate. The emission takes place whether or not a voltage is impressed on the plate-filament circuit, and depends only upon the filament temperature. The process is much like evaporation in a closed vessel and soon reaches a statistical equilibrium where electrons are leaving and return to the filament at the same rate, that is number per second. Impressing a positive potential on the plate disturbs the equilibrium for it withdraws electrons from the tube. When this voltage is small it withdraws but a relatively small number per second; that is the current is small as in the lower portion of the characteristic. As the voltage is increased the current

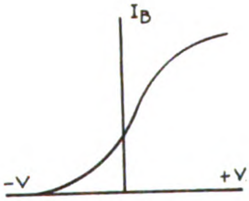


FIG. 15.

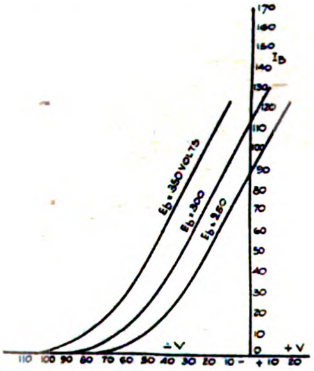


Fig. 16

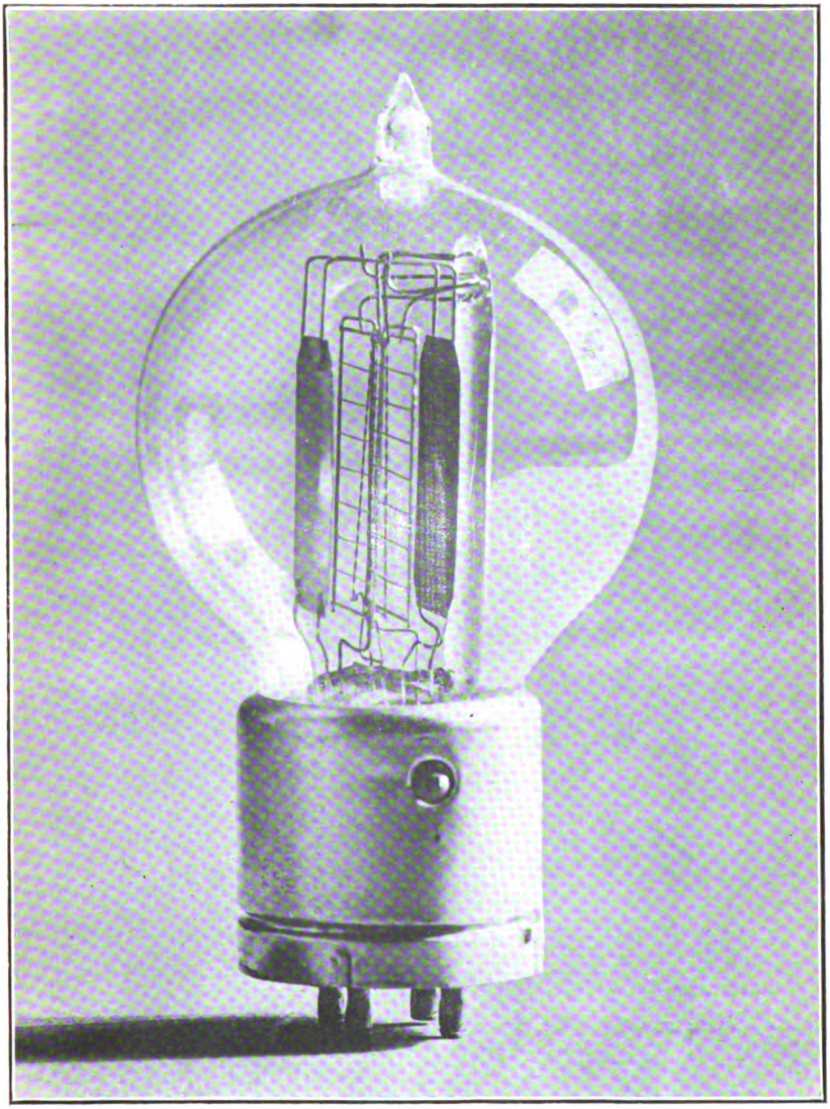


FIG. 13

GHERARDI AND JEWETT]

increases but reaches a steady maximum value for a voltage sufficient to draw across the interspace as many electrons per second as the filament can emit at the operating temperature.

Although the number of electrons per second which pass between filament and plate and hence the current is so limited, the velocities with which the individual electrons move will continue to increase with the voltage. If there is a residual gas in the tube its molecules will be ionized by their collisions with the electrons provided the velocities of the latter are sufficiently high to disrupt the electronic systems of which these molecules are formed. Such ionization, however, increases the number of electrical carriers and hence the charge per second which may be transferred. The presence of gas in a tube is in general, therefore, evidenced by such a characteristic as the full line of Fig. 17.

The voltages involved in the detection of radio signals are much smaller than those met with in telephony so that no serious inconvenience arises from the presence of residual gas. As a consequence, in the production of his early successful audions for radio reception DeForest did not find it necessary to employ all of the known means for producing the highest possible vacuum.

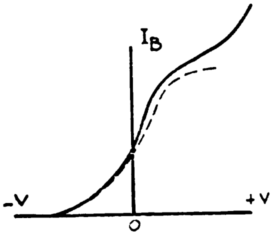


FIG. 17

In dealing with the very much larger energies which obtain under the conditions of telephonic repeater action, it is necessary to adopt methods of manufacture which will insure the removal to a high degree of all gaseous material in the tube, including that which may be occluded in the walls of the tube or the enclosed metallic parts. When such evacuation is accomplished all of the advantages of a pure electron discharge are retained, even for the higher voltages and currents which have to be dealt with in a telephone repeater. In other words, for a given plate voltage there is obtained a wider range of voltage which may be impressed upon the grid without departing from the true thermionic character displayed in Fig. 15.

In addition to securing the necessary conditions in this respect, a large amount of research work has been done by the engineers of the Bell System in producing suitable forms and proportions of tubes to give the best results with the various types of repeater circuits and in devising a type of filament which will insure a maximum of life and a minimum of power consumption for the amplifying tube and at the same time insure a uniform operating characteristic throughout the life of the tube. Further than this, the work has resulted in ability to produce in quantity tubes of exactly the same characteristics, a feature which is of the utmost importance in telephone repeater operation but which is of minor importance in radio work. Non-uniformity in the tubes would very seriously handicap the commercial operation of this type of amplifier since it would require the readjustment of apparatus each time it might become necessary to replace a worn-out or damaged tube.

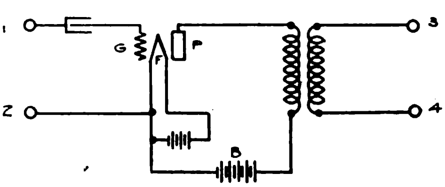


FIG. 18

Not only was the original form of audion deficient as a telephone repeater from the standpoint of its energy capabilities, but the conditions of its use in radio reception were inherently different from those which obtained in a telephone repeater circuit. We may express this fact by saying that for radio detection we make use of the ability of a device to distort a sinusoid, which is impressed upon it, while for telephonic purposes we require the very minimum of distortion.

Associated with the audion in DeForest's use was a condenser in the grid circuit as shown in Fig. 18. The input terminals were *1* and *2* of that figure and the output terminals were *3* and *4* of the repeating coil. If employed as the amplifier in a telephone repeater, the repeating coil serves to impress on the telephone line to which the device is connected the variations in the plate circuit current from the battery *B* which may be occasioned by any alterations in the potential applied to the input circuit. The condenser, however, serves as an electron trap if a sinusoidal e. m. f. is impressed on terminals *1, 2*. Thus imagine that the first half wave of the sinusoid makes the grid negative with respect to the filament. This polarity tends to force electrons from the grid to the filament, but, since electrons are not emitted by the grid, no transfer takes place. Making the grid negative does, however, reduce the current through the plate circuit as we saw in connection with Fig. 15. Now, the succeeding half wave tends to force electrons in the opposite direction, that is from filament to grid, which is a possible direction of transfer in this unilateral circuit. The individual electrons so transferred to the grid cannot pass through the condenser and complete the journey back to the filament although others from the opposite plate of the condenser may be induced to make the rest of the journey. The result is that each positive half wave increases the number of electrons on the grid and its adjoining condenser plate and thus results in a further increase in negative potential. But the more negative the grid becomes the smaller is the current in the plate circuit and the lower the point on the characteristic curve about which we are producing sinusoidal variations.

Obviously, such an action is very satisfactory for detecting the presence in the input circuit of a train of sinusoidal waves of small amplitude since the effect is cumulative. Equally obviously, however, such action may absolutely prevent the passage through the system of a voice actuated train of waves since a word or two may make the grid so negative as to reduce practically to zero the plate current upon the variations of which the transmission of the wave depends.

The correction of the circuit arrangement by the elimination of this condenser, which aided distortion, was but a detail in the broader research which we have made on the application of thermionic devices. This work involved a study of appropriate circuits in which these tubes could be used, of thermionics, of methods of producing high vacua, of gages for indicating the degree of vacuum obtained, a study of various types of filament to secure efficiency and uniformity, and of the physical relations in three-element vacuum tubes of the geometrical form and separation of the electrodes. Some of these researches as for example those of Van der Bijl, W. Wilson, and others have already been published.

The net result of these researches has been our ability to design and construct tubes adapted to any of the purposes of the art of communication. In the final form in which we use a vacuum tube as a telephone repeater we obtain a characteristic relation between input voltage and output current which is free from distortion as far as we can recognize such effects. This is obtained partly by the design of the tube and partly by the proper adaption to it of its associated circuit.

In the first place we arrange that the repeater shall have a constant and finite input impedance by bridging between grid and filament a high resistance. To this resistance current is supplied by a step-up transformer as indicated in Fig. 19. The voltage effective in the grid-filament circuit is then the drop across the resistance. In the second place we generally arrange that the grid shall not be positive at any time in the cycle of the impressed voltage. This is accomplished by inserting a battery, *C*, in the grid circuit. In this way the tube acts as a device for amplifying the impressed voltage and introduces no distortion due to the unilateral conductivity of the grid circuit.

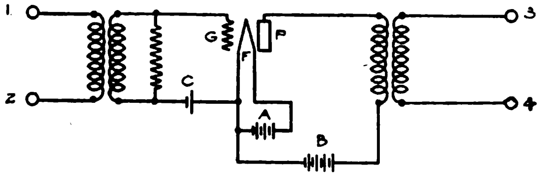


Fig. 19

The characteristic relation between grid voltage and plate current which is shown in the curves of Fig. 16 is obviously not that of a perfect repeater since there is not a linear relation between input voltage and output current. The voltages indicated on these curves are those of the battery in the plate circuit. The condition under which they were obtained is that of no external resistance in this battery circuit so that the voltages are really those which are effective between the plate and filament within the tube. The values of the current in these plots are due to the combined actions of this effective voltage and of the voltage impressed upon the grid circuit. For each of these curves the effective plate voltage is constant and the curve gives the relation between the input voltage and the output current. If, however, there is external resistance in the plate circuit, then the effective voltage between the plate and the filament will not be that of the battery, but will be less by the amount of the *IR* drop in the external circuit. An increase in the grid voltage will not, then produce as large an increase in plate current because such an increase as it would produce if the plate voltage was constant is partially neutralized by the decrease in the effective plate voltage which the *IR* drop occasions. The result is that by properly proportioning the external resistance of the plate-filament circuit we may obtain a characteristic relation between grid voltage and plate current which is essentially linear as shown by the full line curve of Fig. 20.

The requirements for a telephone repeater stated above are

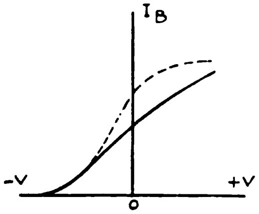


FIG. 20

thus fully met in our construction of the audion and in the circuit arrangement for its operation. In later portions of this paper we shall meet illustrations of its perfection in the report of experiments and commercial operation.

In the case of the audion the control of the electron stream is electrostatic. It is possible, of course, to control such a stream by electromagnetic means since the stream is really a current. Such a control, is, however, inherently less efficient and sensitive than that of the voltage actuated device described. We shall, therefore, give no detailed discussion of such methods but will pass at once to the discussion of devices in which the presence of gas molecules results in an ionization and the consequent presence in the tube of positive carriers of molecular size as well as negative electrons.

III. The distinction between electronic and gaseous repeating elements is not a matter of the presence or absence of gas since an absolute vacuum is unobtainable. It is rather a matter of whether or not gas is an irrelevant and undesirable element or an indispensable one. In the vacuum tube of DeForest gas was not indispensable as we have seen and such gas as was residual limited the range of voltages, throughout which the tube had the desired characteristics when used as a repeater.

III-A. In the repeating element of von Lieben which was invented in Europe somewhat later than the time the audion was produced here, gas is an essential constituent. This device has a Wehnelt cathode, that is a filament coated with oxides of the alkaline earths from which electrons are thermionically emitted. The function of the cathode is not, however, to provide all the carriers as in the case of the filament of the audion but rather to provide means for ionizing the gas present in the tube.

The tube is a three-element device and has in addition to the thermionic cathode, an anode of aluminum (corresponding to the plate of the audion), and an intermediate sieve-like electrode in the form of a perforated aluminum disk.

The function of the sieve is to control the discharge which takes place between the anode and the cathode, in case a potential is properly applied. The stream of electrons which proceeds from the cathode to the anode is impeded by the presence of gaseous molecules. The consequent collisions will result in the ionization of some of the gas molecules if the velocity is sufficiently high and this velocity depends upon the potential which is applied to the circuit. The ionization results in the presence of more electrons which are available for increasing the current and also in the presence of positive ions of molecular size which are similarly available but move in the opposite direction. The introduction of a potential between the filament and sieve permits of an external control of the motions of the electrons and positive ions, attracting the former and repelling the latter or vice versa.

Small changes in the potential applied to the sieve may result in relatively large changes in the ionization and hence in the current in the anode circuit. The device may, therefore, be used to give amplification but for reasons which will appear presently it is not adapted to telephonic work.

Since the tube contains carriers of both kinds a stream of one kind or the other will inevitably flow to the sieve and thus there will be a current in that circuit which will depend for its direction upon the polarity of the applied voltage and for its amount upon the conductivity of the gaseous space within the tube. If the cathode and sieve are used as the input circuit, corresponding to the filament-grid circuit of the audion, then it is evident that the impedance of this input circuit will vary with the impressed voltage. Such a variation will result in a serious distortion and is not in conformity with our requirements for a repeating element.

The presence of both kinds of carriers makes impossible the simple expedient which is so valuable in the case of the audion where the unilateral conductivity of the grid-filament circuit is utilized. Further the pressure of the gas within the tubes is subject to fluctuations which it is almost impossible to control. This results in large variation in amplification. In comparison with the electronic device the von Lieben tube is seriously deficient as a telephone repeater, and the electrostatic control of gaseous devices has not been found capable of as efficient and simple application to telephonic problems as is the electrostatic control of electronic devices.

III-B. The electromagnetic control of gaseous devices has likewise been investigated for telephonic purposes. The oppositely moving streams of positive and negative carriers will be deflected in the same direction by an electro-magnetic field. Provided that the motion of such a discharge stream may be made to alter properly the conductivity of either the circuit of the discharge itself or of some auxiliary circuit a repeating element may be formed.

Some of the early work on such systems is that of Hewitt whose experiments on mercury vapor arcs are well known. The method which he proposed to employ may be seen from Fig. 21, where is shown a tube containing mercury vapor through which a current is passing from the battery *B*. A receiver is connected in series with the battery and the arc. The arc stream itself is controlled by the electromagnet which is excited by the transmitter. This arrangement, which is essentially a very insensitive unilateral repeating device, has never, so far as is known, been made to function as a telephone amplifier. In addition to its inefficiency, this arrangement is undesirable because of noise, distortion and variable amplification.

A later step in the development of an electromagnetically controlled mercury arc repeater was taken by Dr. H. D. Arnold. He utilized an auxiliary circuit for the output and so disposed it that its conductivity was altered in conformity to the motion of the arc stream. In the general idea of using a mercury arc stream and influencing it magnetically, Arnold, of course, follows Hewitt.

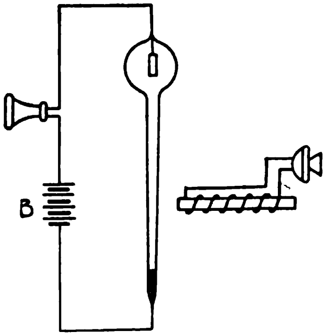


FIG.21

The auxiliary circuit devised by Arnold is at right angles to the arc stream and includes three electrodes, one about the center of the stream and the other two approximately equally spaced on opposite sides as shown by a cross section of the tube in Fig. 22, the main arc stream being perpendicular to the plane of the diagram. The electromagnet is in the plane

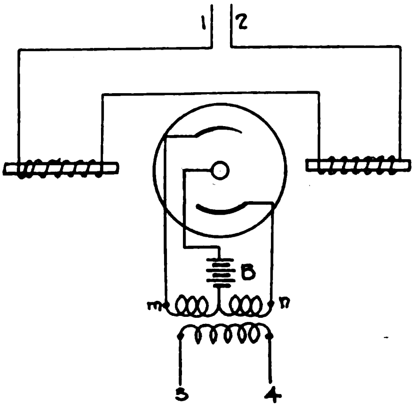


FIG.22

of these electrodes and thus serves to deflect the main arc stream toward one or the other of the side electrodes depending upon the polarity of the magnet. The ions in the main arc stream are available carriers for current between these electrodes and the central electrode if a potential is maintained between them as by the battery, *B*.

In the normal condition, when the arc is undeflected, similar portions of the arc stream are included between the center electrode and each of the side electrodes. The conductivity of the two paths thus offered to the potential of the battery are then equal and there is no difference of potential between the terminals *m*, *n* of the coil, to the center tap of which the battery is connected. In so far as the conductivities of these two branches of this bridge circuit tend to vary as the result of variations in the ionizations of the arc stream no difference of potential will be produced between the terminals of the coil, since both conducting branches will tend to vary similarly due to a common cause. Fortuitous variations in the arc stream are, therefore, not repeated in the external circuit and the difficulty of arc noise is practically eliminated. When, however, the arc stream is deflected by the voice actuated electromagnet, the conductivities of the two branches are oppositely changed and a resultant current circulates.

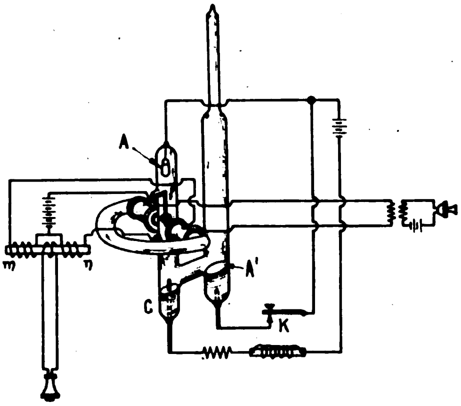


FIG. 23

The device as originally described for patent is shown in Fig. 23. An auxiliary anode, formed by a mercury electrode shown at *A'* is used for starting the arc stream. In this form the arc is struck by tilting the tube and allowing the mercury of the anode A' to run into contact with that of the main cathode C. As the tube is restored to its vertical position an arc is formed between A' and C, provided that the key K, has been closed. Opening the circuit at K allows the arc to form between C and A.

This gaseous device is capable of good amplification and is fairly free from distortion except such as may be introduced by the fact that impedance of. the electromagnet may not be identical with that of a telephone line. It was tried out experimentally on telephone lines but has never been used for any length of time and then only under special engineering supervision. For example, units were installed on the important long distance circuits between New York and San Francisco but were never used commercially.

III-C. The third type of gaseous device which we have investigated as a possible repeater is the negative resistance type. A typical voltage-current characteristic for an arc stream is that of Fig. 24, where the ordinates give the impressed voltages and the abscissas the resulting current.

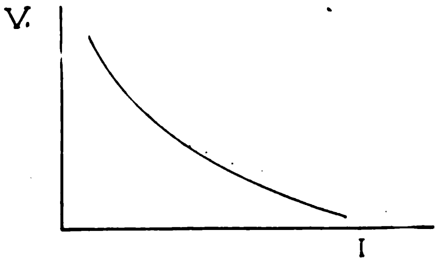


FIG. 24

For an ordinary resistance the slope of the relation of voltage and current is positive in the usual sense, since for any point on the curve dV/dI is positive, and represents a slope of less than 90 degrees measured counter-clockwise from the axis of I. For the arc, however, with its falling characteristic, the slope is negative. The resistance which the arc offers to a change in its condition is thus to be considered negative.

If an arc is connected in series with an ohmic resistance and a source of potential, as shown in Fig. 25, which is essentially that suggested at one time by Hewitt, who dealt with a mercury arc in an enclosed tube, the arc, owing to its falling characteristic, has the effect of making the total resistance in the circuit appear to be less when small current variations exist in the circuit than when steady conditions exist.

The reason for this is that any small increase in current is accompanied by a decrease in the voltage across the arc itself, thus leaving a still greater voltage across the ohmic resistance than would be obtained if the circuit consisted merely of elements obeying Ohm's law. If the source, V, is a transmitter and if there is in the circuit also a receiver, then it follows that the energy received by the latter may, under proper conditions, be greater than that delivered to the circuit by the transmitter. In other words there is a possible telephonic amplification.

The magnitude of the amplification with the Hewitt device obviously depends upon the relative magnitudes of the negative resistance and the external ohmic resistance. The external resistance may in part be that of a telephone line and for that reason this method has been considered as a means of producing telephonic amplification. The negative resistance of the arc can never do more than remove some of the effects of the external resistance. If it could do more, of course, the circuit would "sing." We have found in practice that the system can never increase the loudness of telephone speech unless the line resistance itself is sufficient to stabilize the arc. In practise the arc would have to be connected to various telephone lines, each having different characteristics, and in order that an arc which will amplify, when connected to a high resistance line, shall not "sing" when connected to a line of lower resistance, a certain amount of extra external resistance has to be added to the arc circuit, which resistance will be different for each different type

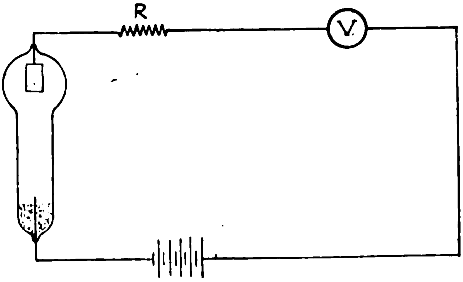


FIG. 25

of line. For practical telephony, therefore, this negative resistance device is not of service.

Even if the possible amplification were sufficient under actual conditions there would still remain the fact that the dynamic characteristic of the arc varies with the frequency of the impressed telephonic waves, giving prohibitive distortion and variable amplification. Further, in common with the other types of gaseous discharge apparatus which we have considered above, the negative resistance device would be too unsteady for practical use.

The two devices which we have found practicable under the exacting requirements of commercial telephone service are the receiver-transmitter element and the three electrode vacuum tube or audion. The electromagnetically controlled arc stream with auxiliary electrodes, which, as indicated above, has been used by us to a limited extent experimentally, and while possessing many of the characteristics of a commerical telephone repeater, is not in its present state of development adapted to general telephonic use. Of the three types, mechanical, electronic, and gaseous the electronic device with its thermionic emission is the most nearly perfect. In fact the amount by which it fails to meet all the requirements for a perfect repeater is so small as to be negligible except under the most rigorous conditions.

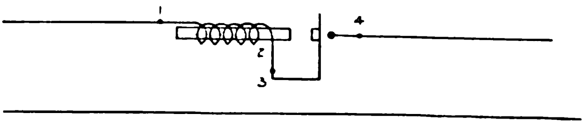


FIG 26

THE REPEATER CIRCUIT

The electrical network by means of which one or more repeater elements may be associated with the telephone lines is conveniently known as the "repeater circuit," as explained above. In two-way operation, such as telephony requires, there may be distinguished three general types of such circuits, of which the bridge or balanced circuit, described earlier in this paper, is the more usual type.

The other types do not depend upon balance for their successful operation. One of these is commonly called the "booster." Fig. 26 shows one form of series booster, in which the input and output of the element are connected in series with each other and with the line. A form of shunt booster is similarly indicated in Fig. 27. A large number of other forms of booster circuit are possible. Negative resistance devices are by their nature adapted to the booster scheme of connection.

In the case of booster circuits there is, for operation without singing, a limiting relationship between the amplification for which the element is adjusted and the impedance of the line in which it is connected. Part or all of the output currents from the element must flow through the input circuit of the element itself, and thus the amplification of the incoming telephonic current depends upon the "building up" of currents in the circuit by the interaction of input and output. It is obvious that if the lines do not offer a sufficient load such a circuit with its element may act as an oscillation generator, that is, there may be singing.

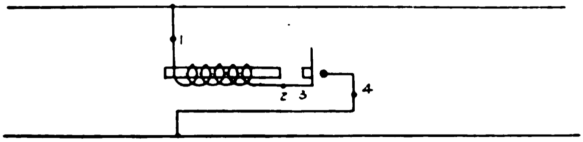


FIG. 27

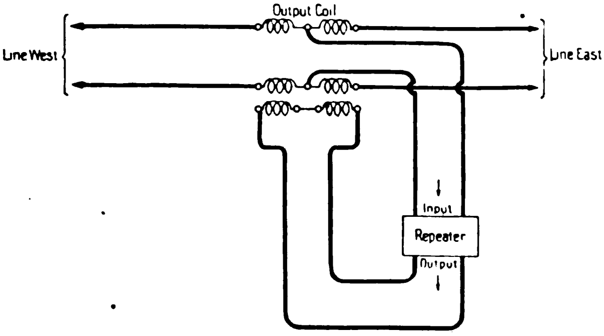


FIG. 28

The third type of repeater circuit is somewhat analogous to the single line repeater of telegraph practise. Incoming voice currents operate sensitive relays which switch the terminals of the element according to the direction from which the voice currents originate so that the circuit is equivalent at any instant to a one-way repeater circuit.

These types of circuit, which do not depend upon balance, have in general been found not so desirable for practical use as the bridge type of duplex circuit and will not be discussed in further detail.

Of the bridge type we may distinguish two classes depending upon whether a single repeater element is used to amplify transmission in the two directions or whether separate elements are used for the opposite directions. The typical circuit shown in Fig. 28 is obviously of the first class. Such circuits we may call "21-type," indicating two-way, one-element circuits. The other class, which we shall discuss a little later, is generally known as the "22-type", since it is a two-way, two-element circuit.

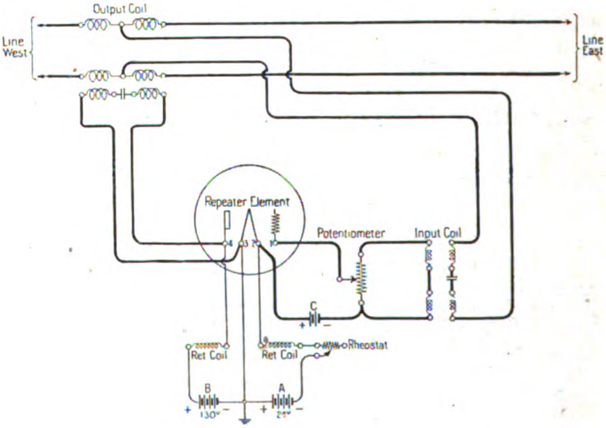


Fig. 29

The input and output terminals of the element in the 21 type circuit, Fig. 28, may obviously be interchanged without altering the physical operation of the circuit, in which case the element transmits to the two lines in parallel instead of in series. The choice between these two connections is influenced largely by the ease with which, through the medium of repeating coils, the input and output impedances of the element may be made similar to the impedances of the network to which they are connected.

A practical form of the 21 circuit is shown in Fig. 29 with its associated vacuum tube amplifier. The incoming energy is supplied through an input repeating coil, between which and the telephone lines is interposed a "filter," not shown in the figure. This filter, of which many satisfactory types have been invented by Dr. G. A. Campbell, is a physically periodic structure, consisting of similar networks in series, which is so designed as to discriminate against the passage of sinusoidal currents of frequencies above or below the necessary telephone range and thus prevents the element from receiving currents which arise from the simultaneous use of the metallic circuits of the telephone line for telegraph currents or other signal currents. The potentiometer is introduced to regulate the gain occasioned by the element. Retardation coils and condensers serve to prevent cross-talk into adjacent telephone circuits and to permit the use of a common battery to supply all the repeater sets at any repeater station. A rheostat is also introduced, as shown, to control the heating of the filament and thus its thermionic emission.

Before proceeding to describe the 22 type circuit we may well restate the physical operation of the 21 type in terms somewhat different from those used in our introductory discussion of the circuit. Let us follow the telephone current, assuming for the moment that it is traveling from west to east. The current that comes to the repeater from the west is partly transmitted through the circuit to the line east but the larger part of it is divided between the input and output circuits of the telephone repeater element. The energy which flows into the output circuit is merely dissipated. The energy which flows into the input circuit is amplified by the repeater element and the amplified current passes to the "output coil." At this point if the line west and the line east are similar in characteristics, the energy divides, half going to the east and half to the west. The half that goes west, that is, towards the direction from which the transmission came, serves no useful purpose. The half that goes east (combined with the small amount of energy that passed directly through the repeater) may be many times larger than the original energy coming from line west and is the useful amplified transmission.

When the lines west and east are identical in characteristics, it is evident by symmetry that there is no voltage set up across the input circuit, and there is, therefore, no possibility of a "singing" condition no matter how large amplifications are employed. This circuit therefore permits two-way transmission over similar lines.

In case, however, the line west and the line east are different in their impedance characteristics for any part of the telephone frequency range, then for such frequencies there will be voltages set up across the input circuit due to current flowing from the output circuit and a tendency towards singing and distortion. The conditions which hold when such unbalances exist will be discussed later.

The duplex bridge circuit, as we saw from our earliest discussion, is applicable as a terminal circuit whereby two-way transmission may be had over a single pair of wires. (See Fig. 3). In such operation the telephone line is balanced by the inclusion in the opposite arm of the bridge of an artificial line of similar impedance-frequency characteristic. At a repeater station we may, therefore, terminate both incoming lines by bridge circuits, balance each line by an artificial line, and operate both lines as a through circuit for two-way conversations provided we connect the input branch of each bridge to the output branch of the other. In connecting the input terminals of one bridge circuit to the output terminals of the other bridge circuit we may introduce a one-way amplifier as shown in Fig. 30.

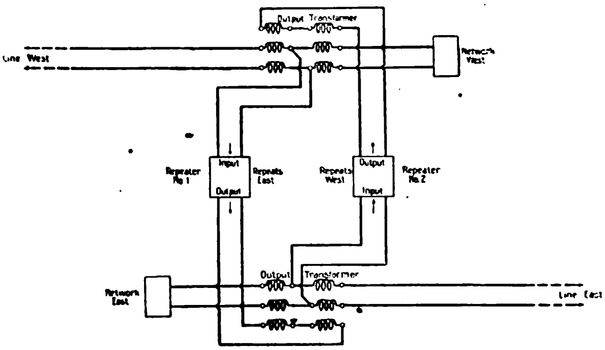


FIG. 30

The resulting circuit is the 22-type defined above, although its evolution did not follow the line which we have just followed for simplicity of discussion. It will be noted that this circuit makes use of a separate repeater element for transmission west to east from that used for transmission east to west, that it requires two "output transformers," and that each line, instead of being balanced by the line in the opposite direction, is balanced by an artificial line indicated as "network west" or "network east." Assuming again the transmission to be coming from the west, we trace the currents through the repeater circuit as follows: A small part of the energy goes through into the network west; the largest part, however, is divided between the input circuit of repeater No. 1 and the output circuit of repeater No. 2. That part which enters the output circuit of repeater No. 2 is dissipated without doing useful work. The part reaching the input of repeater No. 1 is amplified and the amplified energy flows through the output transformer connected to line east. The "network east" is made to have as nearly as possible the same impedance as the actual line for the full range of telephone frequencies. If the balance were perfect, there would be no voltage whatever set up across the input circuit of repeater No. 2, and therefore no possibility of setting up a singing condition whatever values of amplification were used.

Actually, however the balance can never be absolutely perfect, so that there will be a certain voltage set up across this input. This will, in turn, be amplified by repeater No. 2. These amplified currents will then flow through the output transformer connected to the line west. If the "network west" has exactly the same impedance as the line west, then the energy will equally divide between the two and there will be no voltage set up across the input circuit of repeater No. 1. This condition will then prevent any possibility of a singing condition being set up. Again, however, there will be in any practical case some unbalance so that a small voltage will be set up across this input circuit. If the two unbalances involved (*i. e.* line east against "network east" and line west against "network west") are sufficiently large, it is evident that the telephone currents have a closed path through the two repeaters and through these unbalances so that a singing condition may be set up.

This circuit is, however, very much more stable than the 21-type circuit. It will be noted that if either of the networks exactly balances its line, there may be any degree whatever of unbalance between the other network and its line without permitting singing. In general, the fact that the singing condition requires two unbalances simultaneously leads to a more stable condition.

There is another property of the 22-type circuit which is of great importance in connection with tandem operation of repeaters, that is, when two or more repeaters are used at different points in a line. As pointed out, transmission coming from the line west and reaching a 21-type repeater, as in Fig. 28, will result in an amplified current being sent out towards line east; but it will also result in an equally large current being sent back into line west. In the case of the 22-type, however, if the transmission comes in from line west and the balance between network east and line east is good, there will be very little energy sent back into line west. As will be pointed out in more detail below, under "Tandem Operation of Repeaters," this feature has a large advantage as the energy sent back into line west would react on any other repeater which was in circuit in that direction.

A 22-type circuit with vacuum tube repeater elements connected into it is shown in Fig. 31.

In connection with the presentation of the 22-type circuit it is interesting to note that this circuit, which is today the best known means of producing two-way telephone repeater operation with one-way amplifying devices, is the invention of Mr. W. L. Richards, one of the engineers of the Bell System, who devised and patented the arrangement in 1895—years before successful telephone repeaters were available for utilization in telephone systems.

BALANCING OF LINES

As pointed out above, the 21-type circuit depends for its stable operation on the balancing of the telephone line east against the telephone line west, and the 22-type circuit depends on the balancing of each of the telephone lines against an artificial line or "network." "Balancing" requires that the two lines or the line and its artificial line which are balanced against each other shall have closely the same impedance for the whole range of telephone frequencies.

Assuming that we have repeater elements which can give us sufficient amplification without appreciably affecting quality it is evident that the amount of amplification which we can get in any practical case depends on the degree to which this balance condition can be carried. This in turn, as will be more evident after reading the further discussion, depends on line conditions. It is then the line conditions, rather than the repeater element or its circuits which finally limit in every practical case the amplifications which can be obtained with a repeater.

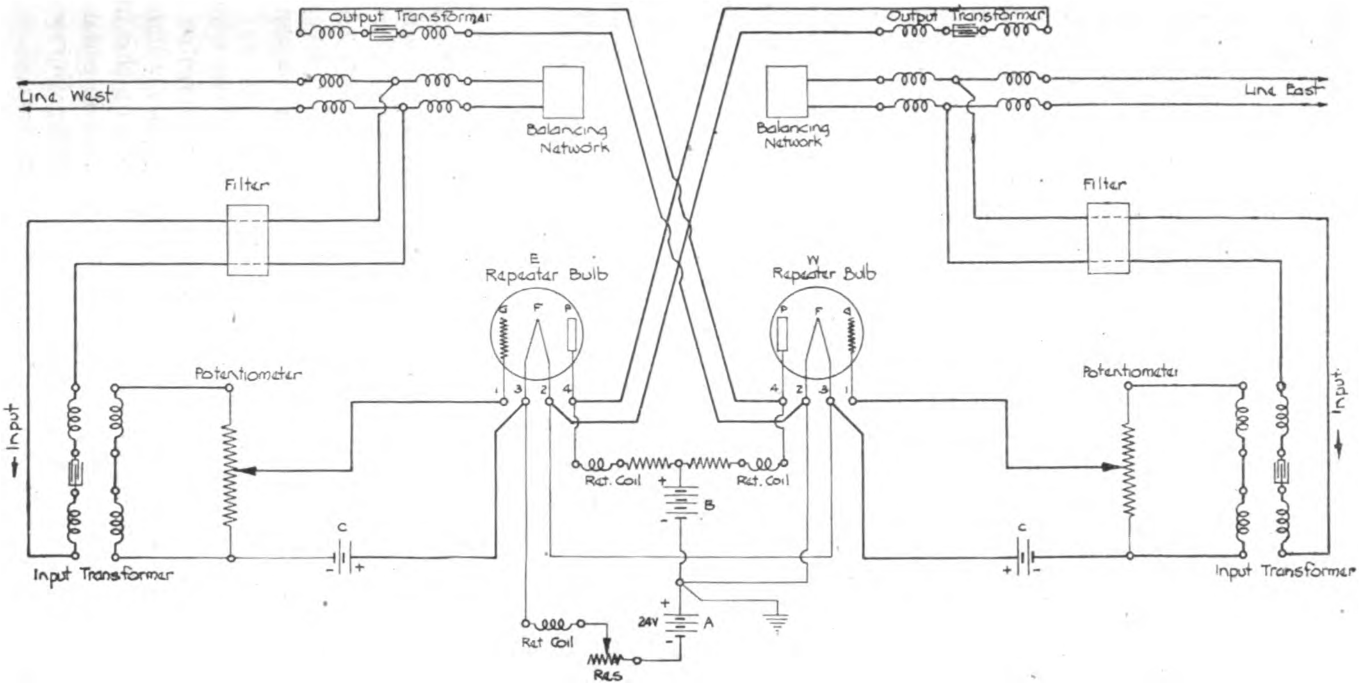

Output Transformer
Output Transformer
Line West
Line East
Balancing Network
Balancing Network
Filter
Filter
E
Repeater Bulb
W
Repeater Bulb
G
F
P
P
F
G
1
3
2
4
4
2
3
1
Potentiometer
Potentiometer
Input
Input
Rst. Coil
Rst. Coil
B
C
C
Input Transformer
Input Transformer
24V
A
Rst Coil
Res

Fig. 31

Let us consider, therefore, what the impedance of a telephone circuit looks like as seen from the repeater terminals.

TELEPHONE LINE IMPEDANCE

If we take a very long No. 8 B. w. g. open wire circuit, which is the largest size of copper in general use in the telephone art, and suppose this circuit to be absolutely uniform in its characteristics, then its impedance, that is, the ratio of the voltage applied across it to the current entering it will be as shown by Curves 1 and 2 in Fig. 32, in which curve 1 gives the resistance and curve 2 the negative reactance of the impedance.

For such a line we can make up a very simple form of network which has approximately the same impedance and can be used for balancing in a repeater circuit. Curves No. 3 and 4 of Fig. 32 indicate the impedance of a network consisting merely of a condenser in series with resistance. It will be noted that even this simple circuit is a very good approximation of the impedance of a long line except at low frequencies. Curves Nos. 5 and 6 show the impedance of a somewhat more complicated network, as indicated on the diagram, which gives a very good approximation over the whole telephone frequency range.

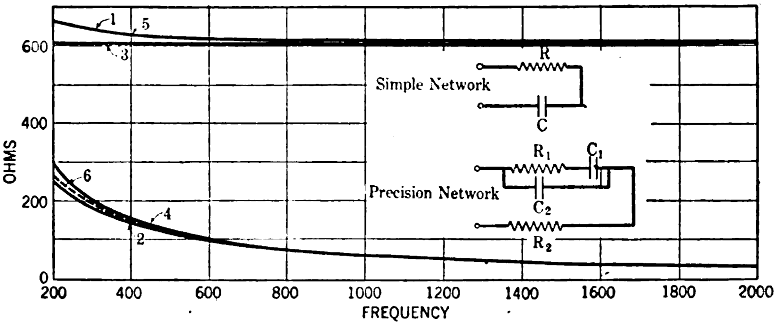


FIG. 32—NON-LOADED NO. 8 GAGE OPEN WIRE LINE

In a practical case every line has slight irregularities which affect somewhat its impedance. An impedance curve for an actual line which is, however, comparatively regular, is shown by curves 1 and 2 of Fig. 33. The measurements on this line were made with the end of it closed through an impedance similar to that of a long length of the line itself. Curves 5 and 6 are copied in from Fig. 32 for comparison.

It is difficult, however, to keep a long open wire circuit free from short stretches of cable. Fig. 34 shows both components of the impedance of a No. 8 gage circuit having a total length of about 165 miles with the distant end closed as before through an impedance equal to that of a long length of the line itself, but with 1¼ miles of underground cable at a point 105 miles from the end at which the measurements were made.

It would evidently be more difficult to make a network having the same impedance as this. It can be done, however, fairly simply by building an artificial line representing the 105 miles from the sending end to the place where the cable is located, putting in series an artificial line representing the cable, and putting beyond the artificial line an impedance network simulating the impedance of a long line, which might be in this case merely a resistance in series with a condenser.

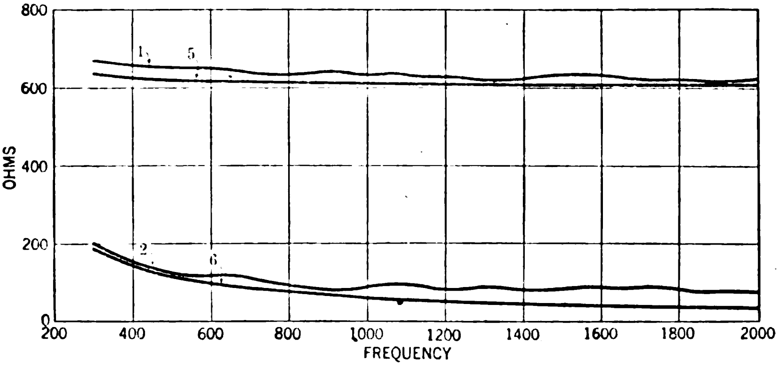


Fig. 33—Non-Loaded No. 8 Gage Open Wire Line

If a line has many irregularities, however, the setting up of a balancing network, while always theoretically possible, would become very expensive and inconvenient. A fundamental requirement, then, in obtaining good repeater action on a line is the maintenance of a high degree of uniformity in the electrical characteristics of the line.

In this particular case the irregularity caused by the cable can, to a considerable extent, be overcome by inserting in the cable one or more loading coils to make the impedance of the cable approximately that of the open wire line. In this actual case a single coil was cut into the cable near its mid-point, and the measured impedance after this had been done is indicated in Fig. 35. In this figure the curves after loading are shown in heavy lines and the old curves are indicated in lighter lines for comparison.

In the case of loaded lines the problem of maintaining sufficient regularity in the electrical characteristics to give a satisfactory impedance curve becomes considerably more difficult, due to variations in the inductances of the loading coils and in the distances between these coils. To illustrate this a number of impedance curves of loaded circuits will be given showing the effects of their irregularities on the impedance characteristics. In these curves, for simplicity, only the resistance component will be shown, as the reactive component is considerably smaller and goes through about the same irregularities as does the resistance curve.

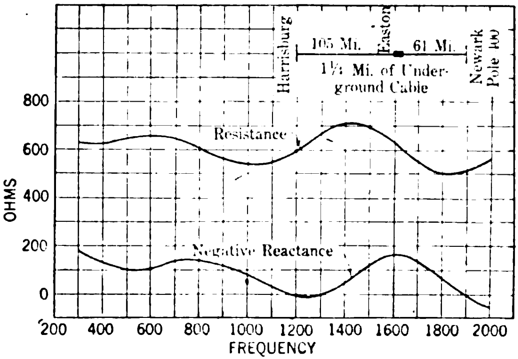


Fig. 34—Harrisburg to Pole 400 Newark, Wires 23/24 Coil out at Easton

Fig. 36 shows an impedance characteristic of an open wire line loaded at approximately 8-mile intervals with loading coils having approximately ¼ henry each. This circuit would give commercial service from a transmission standpoint. It will be noted, however, that its impedance characteristic is extremely irregular, and it would be difficult to obtain gains from a telephone repeater operated in conjunction with it.

Fig. 37 shows the resistance of a circuit of similar constants representing a less extreme condition of irregularity. This would have been considered, before the advent of repeaters, a reasonably good circuit so far as irregularity is concerned. These irregularities were due largely to comparatively small variations in spacing of loading coils and in the inductances of the loading coils. Loading coils have to be placed on a telephone circuit at particular points in the transposition layout of the circuit in order to prevent crosstalk between it and other circuits on the same lead. It is difficult, however, exactly to space transpositions in view of the variations in the route taken by a line, lengths of cable, junction points with other lines, etc.

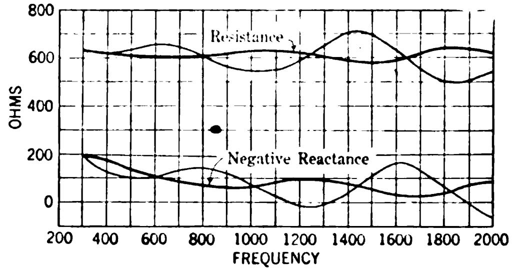


FIG. 35—HARRISBURG TO POLE 400 NEWARK, WIRES 23/24 COIL IN AT EASTON

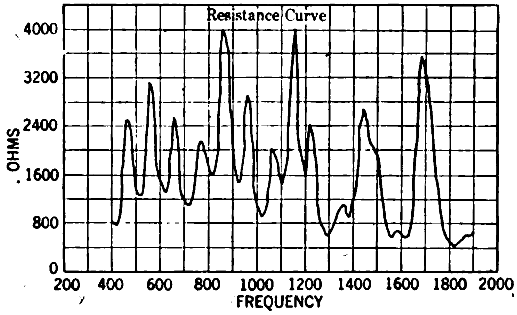


FIG. 36—SECTION OF TRANSCONTINENTAL CIRCUIT PITTSBURGH TO NEW YORK BEFORE "CLEARING UP"

This led in the past to variations in the lengths between the successive loading points. Aerial loading coils are exposed to current surges due to lightning, and with some of the types of coils which have been put into use this has led to variations in their inductances. For any given frequency it may be that the effect of a large number of such irregularities are cumulative in raising the impedance of the circuit for that frequency, whereas with another frequency only slightly removed from the first, the effect of the irregularities may be to reduce the impedance. The result then with such impedance is indicated in Fig. 37 where the variation was due not to a few large irregularities, but to a large number of small irregularities.

This particular circuit was one of those entering into the transcontinental line, so that it was very carefully gone over, retransposed where necessary, the loading coils replaced by others having a particularly high degree of stability and uniformity and the spacings made very uniform. The result of this work is indicated in Fig. 38 in which the dark line shows the impedance after this work had been done and the light line is a repetition of Fig. 37 for comparison. The circuit will now permit of large gains with repeaters.

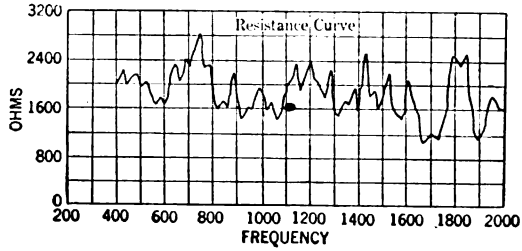


Fig. 37—Section of Transcontinental Circuit Pittsburgh to Chicago before "Clearing Up"

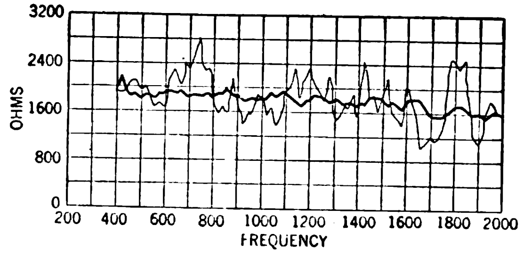


Fig. 38—Section of Transcontinental Circuit—Pittsburgh to Chicago after "Clearing Up"

In the cases where a large variation in impedance is due to one or more large irregularities, the impedance curves often offer a very interesting and convenient method of determining the point at which irregularity exists. For example: Fig. 39 shows the impedance of a circuit as measured from one end, the large wave-like variation being due to defective apparatus at some point in the circuit. By measuring the frequency range between successive "humps" on this "wave" it is possible to determine the distance from the sending end to the point of irregularity. In practical work many cases have arisen where omitted or defective coils or other irregularities have been located in position by this method.

In maintaining this uniformity of the characteristics of the line, one of the largest difficulties is caring for short lengths of cable which may occur in the line at river crossings, in going through towns, etc. It has sometimes been difficult to explain to those outside of the telephone field, but who are acquainted with the fact that by loading and telephone repeaters we can talk through long lengths of cable, why it is that we have so much difficulty with short lengths of cable which come into our open wire circuits, and why we are averse to cutting such short lengths into important long distance lines at villages and at crossings of railroads, power lines, etc. Considering, however, that a 500-ft. length of cable has as much capacity as three-quarters of a mile of open wire, it is evident that even a short length of cable has a very large effect on the operation of any

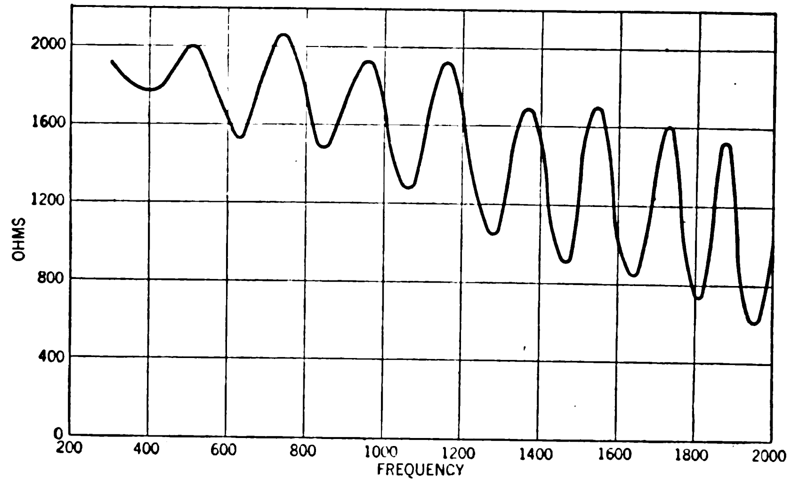


FIG. 39—LOADED NO. 8 GAGE OPEN WIRE LINE

NOTE: This irregularity was caused by defective apparatus located at a distance of about 15 sections from terminals at which measurements were made.

repeater on the line. In laying out a circuit, such short lengths of cable can be partially corrected for in the spacing of the loading coils. Changes made after a line is laid out are of course much more difficult to take care of.

In cable circuits the problem of maintaining uniformity is similar to that of open wire lines, requiring very accurate spacing of the loading coils and requiring loading coils of very uniform characteristics and of high electrical stability.

BALANCING ARTIFICIAL LINES

Assuming, then, in any case, that the lines have been made as uniform electrically as is economical, there is the problem of constructing artificial lines (or networks, as they are generally called) which shall have within a desired degree the same impedance as the actual line. It should be noted that these artificial lines do not need to have transmission characteristics corresponding to the actual lines, but need to have only the same impedance characteristics.

A very simple form is that indicated above for use in balancing a non-loaded open wire line, consisting of a single resistance in series with a single capacity. As already noted, a better approximation for a non-loaded open wire line can be made by adding another resistance and condenser as shown in Fig. 32.

For loaded lines, it is necessary to use a somewhat more complex artificial line, although here again the basic form is comparatively simple. Fig. 40 shows in light lines for comparison an impedance curve much like that of Fig. 38, and in heavier lines, the impedance of an artificial line consisting of two condensers, a resistance and two inductance coils arranged as indicated by the diagram in this figure. For completeness both the resistance and reactance of the impedance are shown in the figure.

In the case of a loaded line the impedance depends very markedly on the place in the loading section from which the circuit is measured. In practise lines are generally terminated either at mid-section or at mid-coil, since these points are symmetrical points in the loading and make for maximum flexibility in connecting circuits together. Most of the figures in this paper were taken at mid-coil.

It is evidently necessary that the balancing line should balance not only the actual line itself, but any apparatus between the line and the point at which the repeater is applied, so that all coils, composite sets or other devices used in series with the line must be, with the necessary precision, balanced in the artificial lines by corresponding coils, condensers, etc.

TANDEM OPERATION OF REPEATERS

The above discussion has referred particularly to the operation of a single repeater in a circuit. Where several repeaters are used in tandem at different points in a circuit, the same considerations are involved. In addition there is the further consideration that not only can circulating currents be set up involving each repeater by itself, and which may lead to "howling," or to distortion in quality, but such circulating currents may follow paths involving any two or more of the repeaters operating in conjunction. As noted above, the 22 type circuit involving artificial balancing lines has a large advantage over the 21 type for tandem operation, due to the fact that transmission entering it from either direction does not cause a large amount of energy to be thrown back in the same direction, as is the case with the 21 type circuit. There is thus very much less interaction between the repeaters with the 22 type.

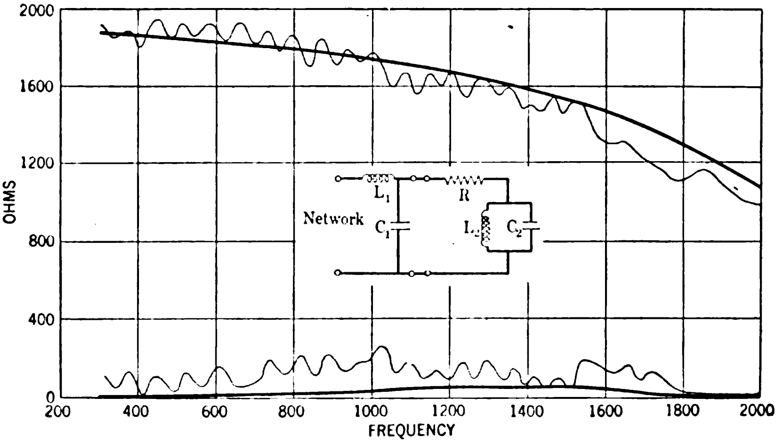


FIG. 40—LOADED NO. 8 GAGE OPEN WIRE LINE ½ COIL TERMINATION

Effective tandem operation of repeaters requires, therefore, a high degree of electrical uniformity, and also requires that the reflection effects between the repeaters and their connected lines shall be reduced as much as possible, so that each repeater brings in as little irregularity to its adjacent repeaters as possible.

THE FOUR-WIRE CIRCUIT

In the above we have considered the application of repeaters in ordinary circuits in which the same pair of wires is used for transmission east as is used for transmission west. After the above discussion regarding balance, it is evident that there would be considerable advantage in transmission if separate pairs of wires were used for transmission east and for transmission west. A circuit of this type, designated as a "four-wire circuit," is shown diagrammatically in Fig. 41.

The term "four-wire" does not mean necessarily that four wires are used, but that different circuits are used for transmission east and transmission west. Each of these circuits may comprise a pair of wires, or may be a phantom circuit, etc.

In a circuit of this kind there will be one-way repeaters in each of the two branches. The two branches must be brought together at the ends for connection to two-wire lines, or to the subscribers' loops. There is, therefore, a possibility for circulating currents to be set up flowing over the two sides of the circuit in series. In order to minimize such circulating currents, artificial balancing lines are used at the points where the four wire connects to the two-wire in a manner similar to the arrangement of the 22-type circuit. It should be noticed that if the total amplification of both branches of the four-wire in series is less than the total transmission equivalent, the circuit cannot "sing." If the balance at the ends is good, the gains may be even greater than the transmission losses without producing singing. As in the case of two-wire operation, however, large distortion may be brought into the circuit by the

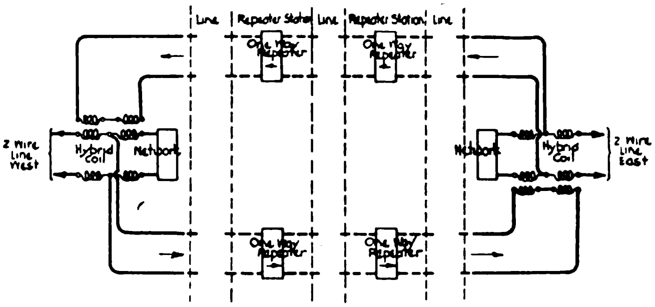
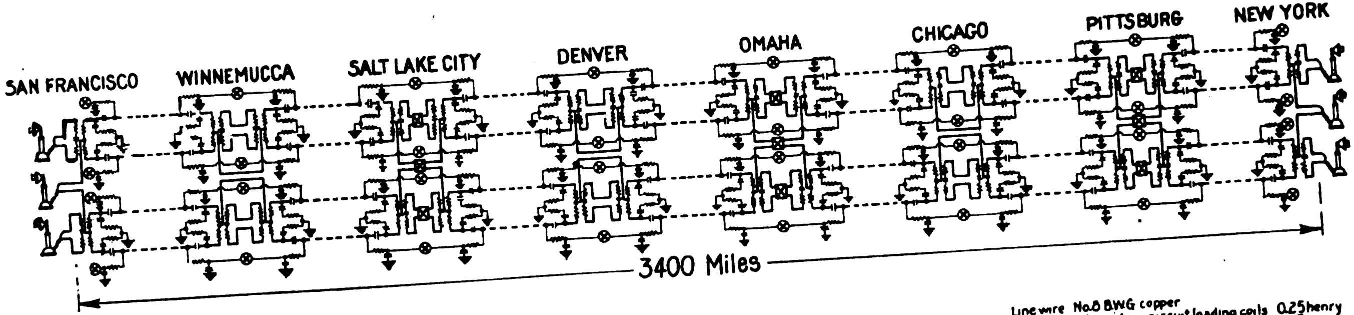


FIG. 41.

NEW YORK – SAN FRANCISCO CIRCUIT
When Set Up for Through Telephone and Telegraph Circuits
Simplified Diagram



Line wire No. 8 B.W.G. copper
Inductance of side circuit loading coils 0.25 henry
" " phantom " " " 0.15 "
Spacing of loading coils 8 miles

Line equivalent = 56 miles of standard #19 ga. cable
Apparatus loss = 7 " " " " " "
Total equivalent = 63 " " " " " "
Total repeater gain = 42 " " " " " "
Resultant equivalent = 21 " " " " " "

This circuit provides for three simultaneous telephone conversations between New York and San Francisco. At the same time it provides for four telegraph messages in each direction.

Telephone repeaters indicated by ⊠
Telegraph apparatus " " ⊗

FIGURE 42

circulating currents even when the amplifications and balance are not such as to produce singing.

Circuits of this kind evidently use twice as many wires as ordinary circuits. They permit, however, the use of smaller wires. It is a question of economics then, as to whether a circuit of this kind proves in in any practical case. For long distance cable operation, and for other special cases, there are conditions where we find that these four-wire circuits have a field of use.

METHOD OF APPLYING REPEATERS

In the practical operation of repeaters there are two methods of connecting them into lines which have come into general use. These are:

(a) "Through line repeaters."

(b) "Cord circuit repeaters."

The through line repeater is one which is associated with a particular line and connected directly into the line. The operators, therefore, have no control over it. It is generally set to give a definite amplification, depending on the characteristics of the line.

The cord circuit repeater is connected into a cord circuit under the control of an operator. The two ends of the circuit generally appear before the operator as two plugs which she may connect into any pair of circuits terminating before her which are in proper shape for repeater operation. The amplification given by the repeater is generally under her control, the amplification in each case depending on the pair of circuits which is connected together.

Where the circuits which may be used with a cord circuit repeater vary considerably in characteristics, so that the same artificial balancing lines will not work satisfactorily with all of them, various arrangements are used so that proper balancing lines will be connected into the circuit corresponding to the actual lines to which the circuit is connected. The commonest arrangement for doing this consists in having a jack in the switchboard immediately below each jack to which a toll line connects. This extra jack has connected to it an artificial line corresponding to the actual line. The repeater circuit then terminates in double plugs so arranged as to pick up both the actual and artificial lines simultaneously.

PRACTICAL RESULTS OBTAINED

As already noted, the amount of gain which may be obtained in any practical case now depends almost entirely on the degree of electrical "uniformity" which it is economical to maintain in the telephone circuits to which the repeaters are connected, since we can obtain within practical limits as large amplifications in the repeater elements as we desire.

We have already indicated the large effect which this electrical uniformity requirement has had on the design of loading coils, and on practises with regard to their use. About every feature of open wire and cable construction and office equipment which affects the electrical characteristics of the circuits has been in some way affected by this repeater requirement. Not only in the design and construction, but also in the daily operation and maintenance of circuits with repeaters, this requirement has to be kept constantly in mind.

At the present time more than 1000 telephone repeaters are in service in the plant. We now will describe a number of typical repeater circuits and will indicate the results which are being obtained.

TRANSCONTINENTAL LINE

The circuit over which transmission is given between the cities along the eastern coast and the Pacific coast cities is shown diagrammatically in Fig. 42. Originally there were three repeaters used in this circuit, located at Pittsburgh, Omaha and Salt Lake City. Since that date, largely for flexibility in switching traffic; the number has been increased to six located at Pittsburgh, Chicago, Omaha, Denver, Salt Lake City and Winnemucca. The total gains were only slightly increased by the change. The circuit consists of No. 8 B. w. g. copper conductors loaded at eight-mile intervals with coils of one-fourth henry each. This gives a line equivalent of 56 miles of standard 19 gage cable. There is a further transmission loss due to composite and other apparatus of about 7 miles, the total equivalent being, therefore, about 63 miles. This is reduced by repeaters to a resultant equivalent of 21 miles, which is, therefore, about one-third of the equivalent without repeaters.

The drawing shows the important points on the line, indicates the positions of telephone and telegraph repeaters and indicates the compositing apparatus used in separating the telegraph and telephone currents.

BOSTON-WASHINGTON CABLE

The largest use of repeaters on cables has been in connection with the circuits between the various cities which are served through the underground cable route extending from Boston through Providence, Hartford, New Haven, New York, Philadelphia and Baltimore to Washington. The use of repeaters on small gage cables placed in this subway became of the greatest importance during the war in caring for the tremendously increased requirements for telephone facilities between these large cities along the Atlantic seaboard.

Most of these telephone repeaters are located in the large cities along the route of this cable. At two places, however, Princeton, N. J., and Elkton, Md., the repeater requirements were such as to justify the putting up of buildings especially for repeater operation. Fig. 43 shows an illustration of the building which was put up at Princeton. There are now about 200 repeaters working at Princeton. The ultimate capacity of the building will be over 500 repeaters.

Fig. 44 shows a typical group of repeater racks, each rack carrying two complete repeaters. Fig. 45 shows at the left front and back views of some of these repeater racks. At the right it shows the face of a test board from which the different repeaters and associated circuits may be tested. Fig. 46 shows the power board where the operating currents and potentials applied to the repeaters are measured.

The repeaters shown in the above photographs are of the vacuum tube type. Fig. 47 shows a front view of an installation of the mechanical type repeaters at Providence, R. I. Fig. 48 shows a rear view of the repeater racks.

The longest cable circuits set up along this route are those from Boston to Washington, a total distance of about 455 miles. A typical layout for a circuit of this kind consists of loaded conductors, No. 10 B. & S. gage from Boston to New York, No. 13 gage from New York to Philadelphia and No. 10 gage from Philadelphia to Washington. This circuit has an equivalent of about 30 miles of No. 19 gage standard cable, which by means of repeaters at Hartford and Philadelphia is reduced to about 14.5 miles. It should be noted here that No. 10 gage conductors, are somewhat larger conductors than would now be placed for this business, and are being used because they were available, having been placed before the use of repeaters had been developed to their present effectiveness.

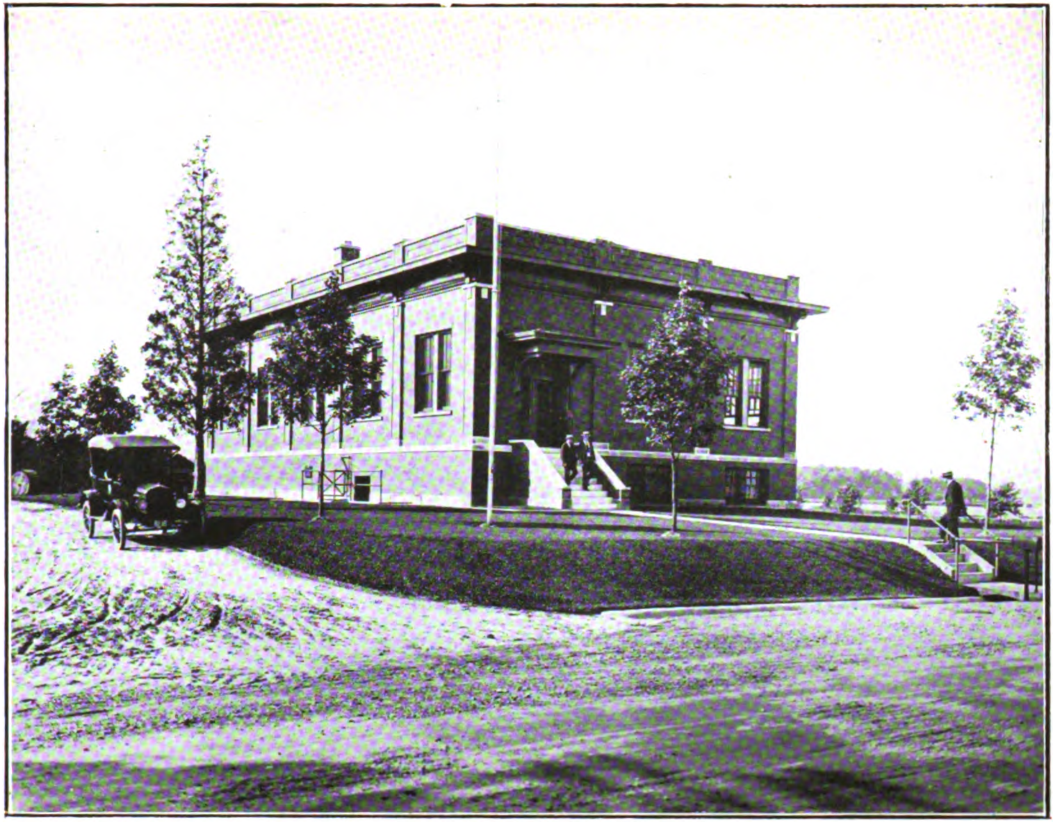


FIG. 43

[GHERARDI AND JEWETT]

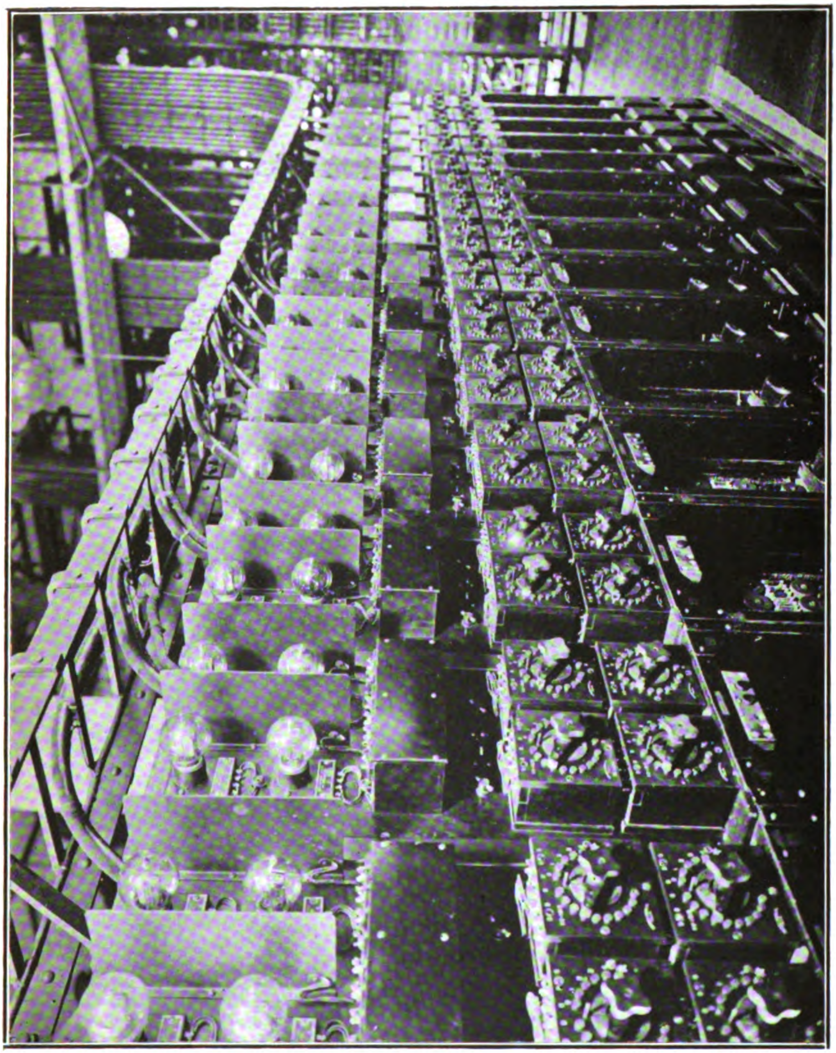
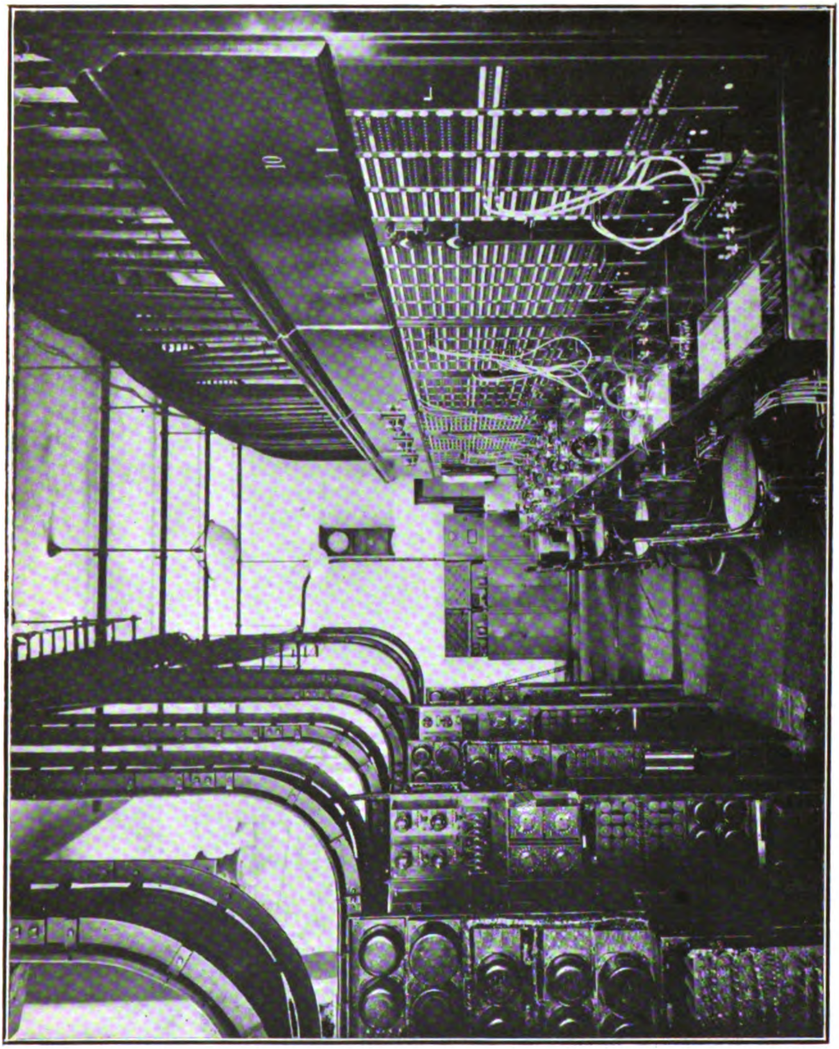


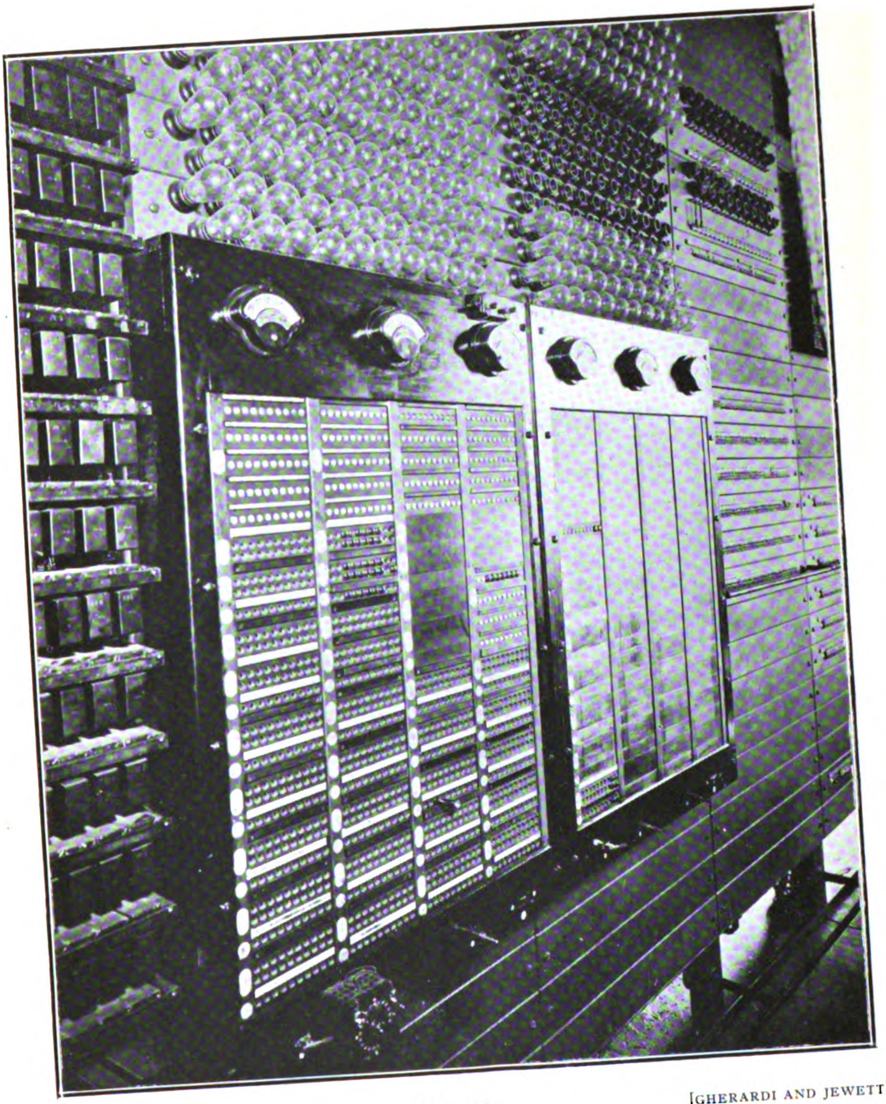
FIG. 44

[GHERARDI AND JEWETT]



[GHERARDI AND JEWETT]

FIG. 45



[GHERARDI AND JEWETT]

FIG. 46

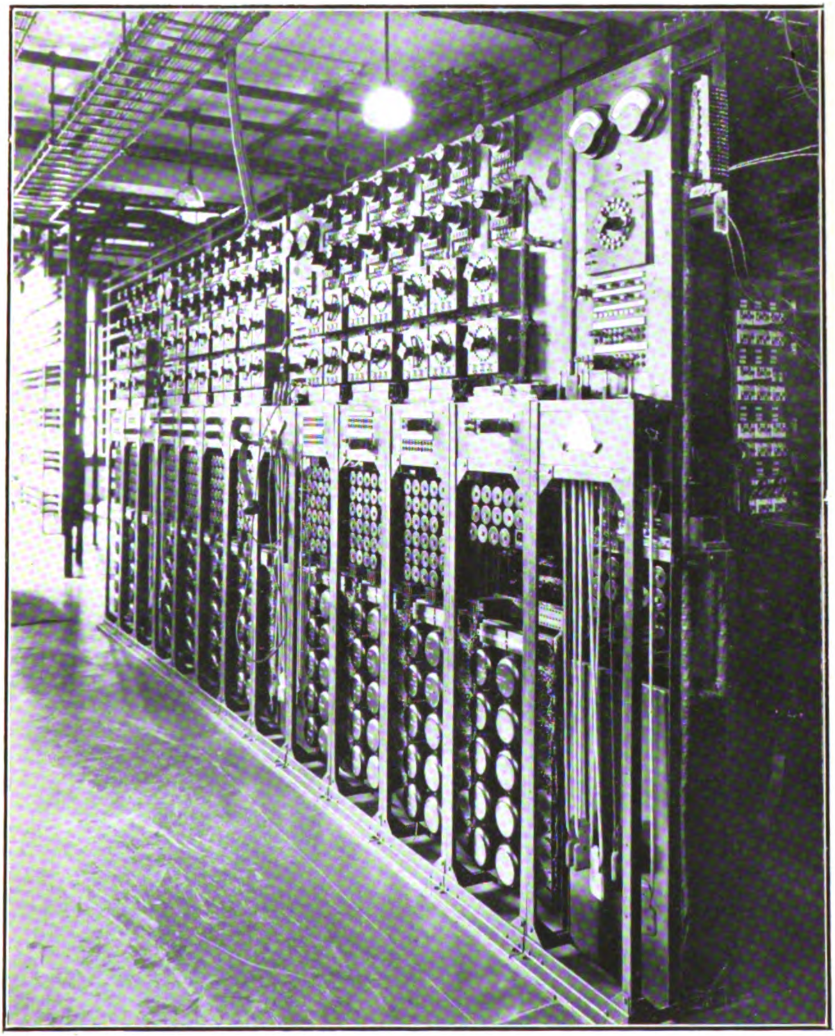


FIG. 47 [GHERARDI AND JEWETT]

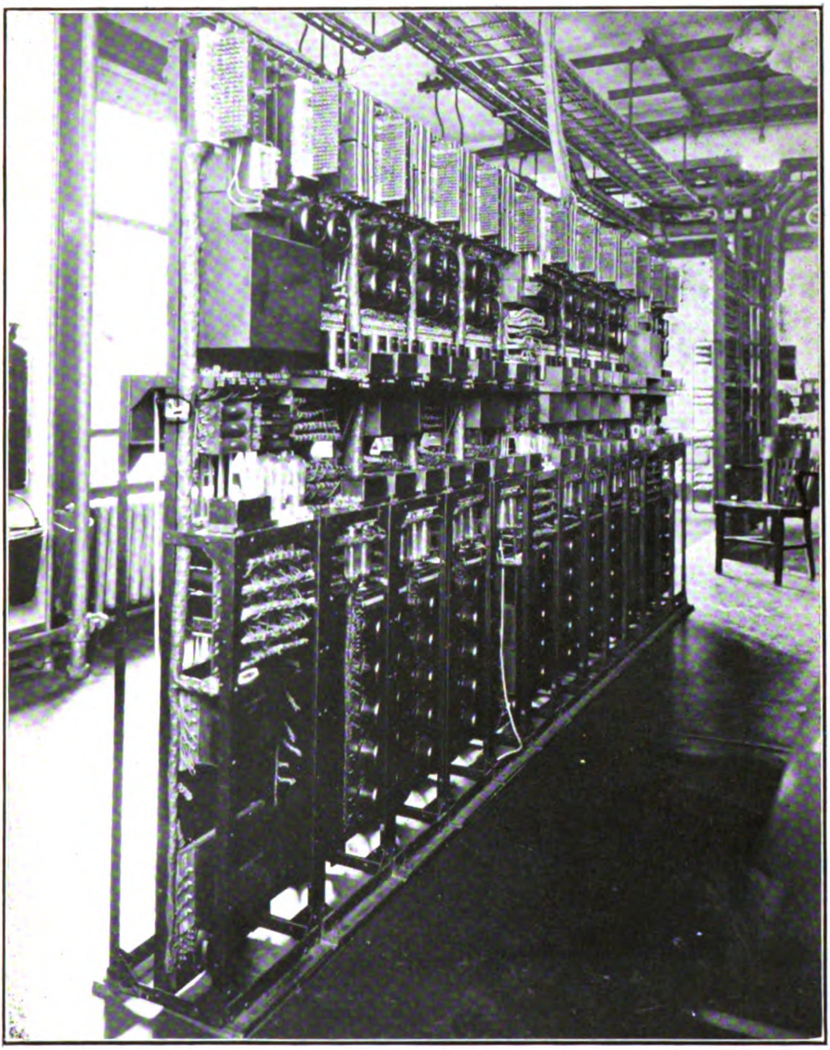


FIG. 48 [GHERARDI AND JEWETT]

The longest circuits electrically, that is, those having the greatest attenuation, which have been operated with repeaters along this route, are New York-Washington circuits, consisting of No. 19 gage cable loaded with coils of about one-fourth henry inductance, spaced at intervals of about 1.16 miles. The distance is about 225 miles. This gives a line equivalent of about 62 miles standard cable. By the use of four repeaters at Princeton, Philadelphia, Elkton, and Baltimore, the equivalent of this circuit is reduced to about 13 miles of standard cable.

The above circuits make use of the 22-type repeaters. Where there is but one repeater in a circuit, however, the 21-type gives, under many conditions, satisfactory service. For example, between New York and Philadelphia, a distance of about 90 miles, a group of circuits is being worked on No. 19 gage conductors, with a single 21-type repeater at Princeton. The circuit without repeaters has an equivalent of about 24 miles of standard No. 19 gage cable. The repeater reduces this to about 14 miles.

SUMMARY

In the foregoing pages we have endeavored to present a short history of telephone repeater development, a statement of the factors which control their successful operation, an idea of the possibilities and limitations of different types of repeaters and repeater circuits, and three or four typical examples of the present commercial line combinations in which telephone repeaters are vital links in the every-day telephone service of the public. These, we believe, will give the members of the Institute a fair picture of the state of the art as it now exists, both technically and commercially.

In concluding the paper it seems only necessary to add a word with regard to the further influence which the telephone repeater is likely to have on telephonic communication in the future.

As indicated in the earlier parts of the paper, the net result of the vast amount of work already done has been to produce amplifying devices capable of taking energy from a local source or sources and under the control of enfeebled telephonic currents from a distant transmitting station deliver back into the telephone line currents which are faithful reproductions of these enfeebled control currents but with many times their energy. Furthermore, the work already done has developed the methods which permit of utilizing the amplifying properties of these repeaters in the various kinds of telephone lines which go to make up the modern telephone network and methods of constructing and maintaining lines to secure maximum efficiency and economy from the use of repeaters. The tools thus at our disposal are of such a character as to permit of our forecasting the changes which their use is likely to produce in the evolutionary growth of the telephone plant. When combined with the benefits to be derived from the loading of cable circuits, the use of the practically perfect repeaters now available puts an entirely different aspect on many of the problems which have confronted the telephone engineer in the past. Not only will there be the opportunity to utilize smaller gage wires than has hitherto been possible but the economical field for underground and overhead toll cables will be greatly extended into the region which it has heretofore been possible to serve only with some form of open wire construction. Viewed from the standpoint of continuity of service alone, this is an advantage of almost inestimable value. Further, the range of reliable and commercially possible long distance telephony will be very greatly extended.

Numerous fields which have in the past been fruitful regions of experimentation have likewise been made obsolete by the development of the telephone repeater. Most noteworthy of these is that looking to the production of powerful or so-called loud speaking transmitters. Many investigators have in the past devoted much effort to the production of this type of equipment, and for many years a large group of telephone engineers, notably those in Europe, looked upon the production of a practical loud speaking transmitter as a key to the solution of long distance telephony. Comprehensive studies by the engineers of the Bell System early convinced us that the solution did not lie in this direction and the success of the telephone repeater is a vindication of the adequacy of these early studies and of the consistent line of development which followed them.

In conclusion, the authors wish to express their appreciation to Mr. E. H. Colpitts, Assistant Chief Engineer of the Western Electric Company, Incorporated; Mr. O. B. Blackwell, Transmission Development Engineer of the American Telephone and Telegraph Company; Mr. A. B. Clark, of the American Telephone and Telegraph Company, and Mr. H. E.

Shreeve and Mr. John Mills of the Western Electric Company, Incorporated, for the very great help they have rendered in the selection from a mass of information of the data for this paper and for their assistance in its preparation.

September 18, 1919

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THE PIEZO ELECTRIC EFFECT IN THE COMPOSITE ROCHELLE SALT CRYSTAL

BY A. MCL. NICOLSON

ABSTRACT OF PAPER

The piezo electric effect is an electro-elastic property of certain crystals. It involves the conversion of mechanical into electrical energy, and also the converse effect. The paper presents an exposition of piezo-electricity and related optical and other properties belonging to these crystals. Special reference is made to the comparatively large piezo electric effects produced by Rochelle salt crystals prepared so as to develop the natural *composite* structure usually associated with substances which have been exposed to shearing stresses, in this case during growth.

Applications of the piezo electric effect in such crystals to the transmission and reception of sound, are described and demonstrated.

INTRODUCTION

THE expression piezo is derived from the Greek "piezein" signifying "to press." It relates to a variety of solids in the crystalline state, which when subjected to change of stress, become electrically polarized. Piezo electricity, includes, also, the reciprocal phenomenon, whereby the same crystals dilate or produce stresses when electric charges are applied to certain regions.

Before discussing the piezo-electric effect in these crystals it will be of assistance to consider first the optical activity exhibited by the same class of crystals.

For example, quartz and Rochelle salt are piezo-electrically active for the same reason that they are optically active, viz., on account of their individual structural asymmetry.

OPTICAL PROPERTIES

It has been known for a century that certain[1] substances either in the crystalline state or in solution possess the power of rotating the plane of polarization of polarized light. This property in the case of the crystal[2] as also of the solution[3] was shown to be due to structural asymmetry. In crystallography this asymmetry is called hemihedrism and refers either to an asymmetric arrangement of perfectly regular and superposable molecules or to an arrangement of molecules which are themselves asymmetric. For example, quartz and other minerals, so far as we know, do not possess *molecular* asymmetry; yet, on account of the right or left handed spiral or other unsymmetrical *structure* prevailing with respect to a principal axis, the optical plane of polarization is correspondingly rotated. When, however, the mineral structure or crystal is destroyed, the optical activity vanishes. On the other hand, the asymmetry of the active organic crystals and solutions resides in the molecule, and although optical activity is not always strongly manifest in the organic crystal, it is generally strong in the solution.[4] Each asymmetric molecule takes part in the rotation. Inasmuch as the molecule may offer a dextro- or laevo-rotation of light, there must necessarily be an asymmetric configuration or "stereo-isomerism." This is generally described as a molecular structure having that kind of asymmetry that is not superposable with its reflected image, possessing neither a center nor a plane of symmetry. In stereo-chemistry these so-called "enantiomorphic" isomers are of three kinds: right forms, left forms, and a mixture of both types which is optically inactive.

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[1] Biot. Societe Philomathique Dec. 1815.

[2] Herschel, Roy. Soc. 1820.

[3] Pasteur, Soc. Chim., Paris. 1860.

A crystal may be built up of one or other of the two *active* isomers—of dextro or laevo asymmetry. The corresponding hemihedral crystal is identified by certain simple marks—such as a particular face which slopes one way in one isomer, and the opposite way in the other, and by other indications. These two classes of crystal differ only in their geometry—as, for example, the right hand differs from the left hand, or as a *right* asymmetric tetrahedron differs from a *left* asymmetric tetrahedron. Chemically, their composition and properties are identical.[5]

Let us consider some other properties in these optical isomers. The crystal form is only one of the many ways in which the symmetrical or asymmetrical arrangement of the molecules may be manifested. We know that some of the physical properties determined by the internal arrangement of the atoms within the molecule, according to this is symmetrical or asymmetrical, may disclose themselves in the crystal;[6] as for example, by selective action of solvents on faces, which are attacked in different ways, by unequal development of the faces, by electrical polarization due to temperature and stresses, etc. If we operate by various physical contrivances on certain faces or edges of a *hemihedral* crystal, then we find a *non-uniformity* in the resulting reaction. The etched figures on the prism will be unsymmetrical, or different in character on the basal planes. Changes in temperature and variations in applied stress will develop socalled analogous and antilogous electric poles on the crystal, and impressed electric charges will produce displacements.

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[4] L. Pasteur, loc. cit., Nernst, Theoretical Chemistry, p. 88, 1911. and J. M. Jaeger: Lectures on the Principle of Symmetry, ch. 7., 1917.

[5] The identity persists so far as they are brought together with bodies which belong to the *symmetrical* class of compounds. But if the isomers are associated with other bodies of the *asymmetrical* class of compounds then their properties differ.

PIEZO ELECTRICITY

The same mechanism in asymmetric crystals which operates on polarized light to rotate the plane of polarization also causes a liberation of electricity when the crystal is elastically deformed, or a dilatation when electric potentials are applied. This mechanism is found only in the hemihedral or hemimorphous crystal possessing either the asymmetric arrangement of the *atoms* in the organic molecule such as the tartrates, sugar, camphor, etc., or the asymmetric arrangement of the mineral *molecules* such as quartz, tourmaline, boracite, etc.

H. and P. Curie[7] discovered the effect and proved that it was due directly to stresses, or changes in the applied stresses, rather than to changes in temperature which, under the name of "pyro-electricity," had been known previously as a thermal-electric property of these asymmetric crystals; and the name "Piezo[8] electrique" was applied. Examples of piezo-electric crystals of the mineral type are shown in the accompanying Figs. 1, 2 and 3,—respectively tourmaline, boracite, and quartz. Tourmaline is hemimorphic hemihedral characterized by having uniterminal crystallographic poles, associated with different faces of the crystal, only alternate ones of which are developed. Boracite is a hemihedral tetra-hedron and represents a cube having four alternate corners truncated. It will be noted that in both crystals there are so-called "sharp" and "blunt" ends or corners. If the crystals be pressed between sharp and blunt poles, definite electrification of these poles results. If the pressure be released a reversal of the electric charge takes place.

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[6] W. H. and W. L. Bragg, X-Ray and Crystal Structure, p. 146., J. M. Jaeger, loc. cit., p. 256.

[7] Compt. Rend. 91, pp. 294 and 383, 1880.

[8] Hankel, Abh. saechs. Ges. d. Wiss., 12, 1881.

Fig. 3 shows a well-known application of the piezo electric effect for measuring small charges. A blade of quartz cut

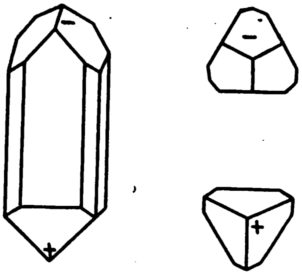

FIG. 1—TOURMALINE

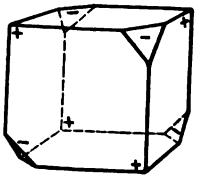

FIG. 2—BORACITE

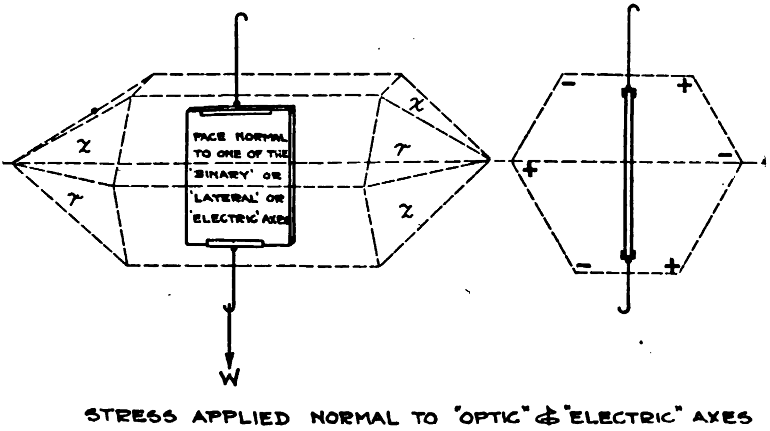
FACE NORMAL TO ONE OF THE 'BINARY' OR 'LATERAL' OR 'ELECTRIC' AXES
x
r
x
r
x
W
-
+
+
-
-
+
STRESS APPLIED NORMAL TO "OPTIC" & "ELECTRIC" AXES

FIG. 3—INDICATING PREPARATION OF THE QUARTZ "PIEZO ELECTRIQUE"

from the crystal as shown, and coated on its sides with tinfoil, or silvered, liberates electricity, the quantity of which depends directly on the weight which is suspended from it. An electrification, with the object, for example, of balancing a charge on an electroscope, may thus be accurately "weighted out." This method is used in the measurement of ionization currents.

The relation between pressure and electric charge for the quartz "piezo-electrique" as given by Curie is:

$$Q = K \frac{L}{l} P$$

where Q = charge in e. s. u.
K = piezo electric constant = 0.0677 e. s. u. per kg.
L = length of coating (along crystallographic axis)
l = width between coatings
P = weight attached in kilograms.

Amongst many mineral and organic crystals investigated by the Curies and others,[9] the crystal of Rochelle salt was found to have the largest piezo electric constant, approximately, 10 e. s. u. per kg. Apparently no other crystal has yet been found to approach the piezo activity of Rochelle salt, parcularly if the crystal is carefully chosen and specially prepared.

In 1917 the Research Laboratories of the American Telephone and Telegraph and the Western Electric Companies commenced an inquiry into application of the piezo electric effect. As an outcome of some of the experimental work performed, it was found that Rochelle salt was susceptible of greatly increased piezo electric activity. An absolute electric charge of 200 e. s. u. per kilogram pressure has been obtained, resulting in potentials as high as 500 volts and alternating currents measurable through a thermocouple. Acoustic tones from a crystal may be heard at a distance of several hundred feet.

Briefly, the increased efficiency is brought about by the following conditions:

1. Selection of particular habit of growth.
2. Desiccation.
3. Development of the crystal into a "composite" polar structure.
4. Application of static compression.
5. Use of electric poles normal to each other.
6. Application of torque.

CRYSTALLOGRAPHY OF "COMPOSITE" ROCHELLE SALT

Rochelle salt[10] crystals are grown from perfect nuclei possessing definite form. The nuclei or seed crystals are immersed in a saturated solution[11] of the salt under identical conditions of temperature. The crystals may be grown by the application of temperature gradients to saturated solutions of the salt or by concentration brought about by its evaporation. The former method, producing a specific type under conditions of rapid cooling, is the method preferred. The crystal may be grown in the mother liquor by suspending from a clean thread, by flotation on mercury, or by being laid on a glass plate. The two last are the methods practised in our laboratory.

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[9] See F. Pockels, Winkelmann's Handb. d. Phys., Bd. IV., p. 783.

[10] The chemical formula for sodium potassium tartrate is $NaKC_4H_4O_6.4H_2O$.

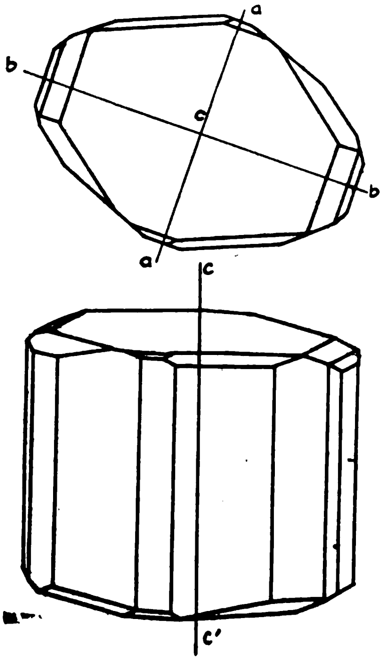

FIG. 4—CYRSTAL GROWN BY SUSPENSION FROM THREAD OR SUPPORTED ON MERCURY

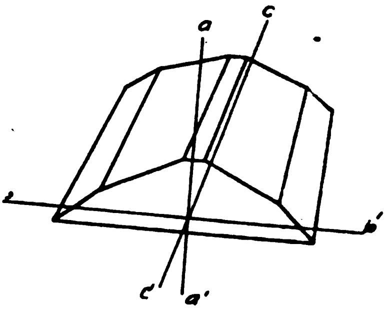

FIG. 5—CRYSTAL GROWN HORIZONTALLY ON A PLATE OR ON MERCURY

Fig. 4 indicates the general appearance of the Rochelle salt[12] crystal. It belongs to the rhombic system is hemihedral and enantiomorphic. It may be possible to classify crystal surfaces into two systems of surfaces or zones which are normal to each other. One system of zones will be parallel with the principal or crystallographic axis *c* and will therefore engirdle the crystal. The other system of zones will comprise the two basal planes parallel with the *a* and *b* axes. In Fig. 4 the zones are shown, respectively, as vertical and horizontal surfaces. In practise, the crystals are grown with the *c* and *b* axes in a horizontal position as is indicated in Fig. 5. This growth forms a particular habit, becoming dominant along the *c* and *b* axes while development along the *a* axis upwards is partially suppressed (on account of the supersaturation and consequent gradation in density of the liquor.[13] In obtaining seed crystals, generally from a previous cropping, we select those in which growth along the *b* axis is fully developed (which happens when the seed nucleus grows with its *c* and *b* axes horizontal). These seeds are square, or nearly so, signifying that the growth along the *b* axis is about as great as, or greater than, that along the *c* axis.[14]

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[11] A density of 1.33 at 50 deg. cent. may be conveniently used and the seed crystal, previously warmed to the same temperature as the liquor, should be applied between 38 deg. cent. and 35 deg. cent.

[12] This drawing was made by Prof. H. P. Whitlock of the Amer. Mus. of Nat. Hist., N. Y. C.

On cooling rapidly,[15] the seed crystal will increase in size from a few grams weight to 50 or 500 grams, according to the volume and density of liquor used. An average size of crystal weighs 100 grams and its axial lengths approximate 65mm. x 65mm. x 25mm. The illustration, Fig. 6, shows a group of crystals of the habits indicated in Figs. 4 and 5.

Crystals thus rapidly grown develop internal stresses producing strain regions symmetrical with the principal axis.[16] The crystal acquires a composite structure[17] closely related to the surface zones referred to and to the electric poles to be developed as now explained.

At each end of the seed-nucleus and along its *c* axis, there appears a pyramid, not always very pronounced in the nucleus itself, which forms a polar terminal,—see illustration of crystal No. 612 in Fig. 7. The pyramids consist of stratifications normal to the *c* axis and to the rest of the crystal structure, the stratification of which ordinarily is parallel with that axis. The electrical performance of the crystal suggests that the crystal molecules throughout the pyramidal regions during growth are subject to forces which turn them, in planes containing the principal axis, through a right angle. This is indicated by the fact that the crystal, after subsequent treatment tending to render more pronounced these pyramid terminations, develops its electric poles[18] in accordance with the two systems of zones previously described. The poles are accordingly at right angles to each other. This signifies that the pyramids are electrically (+) when the rest of the crystal structure is (−) and vice versa. The effect becomes very pronounced when the crystal is subsequently dried in alcohol and baked in an oven.[19]

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[13] Lamethérie,—see; La Genese de la Science des Critaux, H. Metzger, p. 187, 1918.

[14] The thickness of the crystal along its *a* axis is generally 0.4 *b;* this dimension is a function of the density and head of mother liquor.

[15] Growth occurs principally during the first 12 hours, although it may be continued several days during the condition of supersaturation.

[16] These stresses are probably due to contraction as the temperature falls.

[17] Mineralogists have termed this an "hour-glass" marking. The phenomenon is probably due to shearing strains set up by relatively greater contractions of the outer crystal envelops during cooling.

POLARITY AND CRYSTAL DRESSING

The raw untreated crystal possesses a large number of local electric poles which are variable in their piezo electric effect. The desiccated crystal is much stronger[20] in effect and its electric poles are readily found in the case of the composite crystal to reside as described on the crystal surfaces with corresponding signs, respectively, at the "vertical" and "horizontal" zones.

In order to prepare the crystal for piezo electric use its exposed parts are painted over with special varnish, after which waxed tinfoil electrodes are pressed on the crystal as shown in Fig. 8.

SENSITIVE REGIONS OF CRYSTAL

Referring again to Fig. 8, it will be noticed that both basal planes of the crystal are filed slightly concave in the central or polar regions. The object of this is to render salient the four diagonal "horns" or ends of the basal planes, which are found to be the mechanically sensitive regions of the crystal, that is to say, the extreme outer edges parallel with the *b* axis. For the purpose of obtaining an efficient piezo electric

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[18] Plus and minus corresponding with the conventional analogous and antilogous poles.

[19] 90 per cent alcohol, 24 hours; 100 per cent alcohol 6 hours, oven at 40 deg. cent. several days. This treatment reduces the weight 3 per cent.

[20] Aging and compression also improved them slowly.

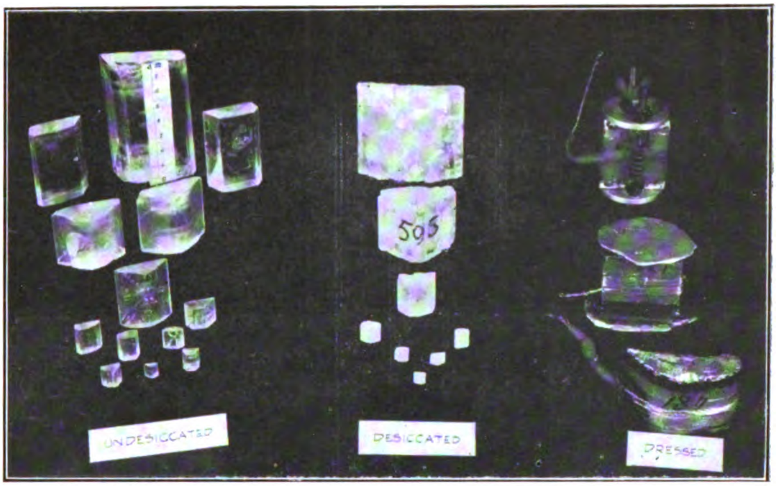
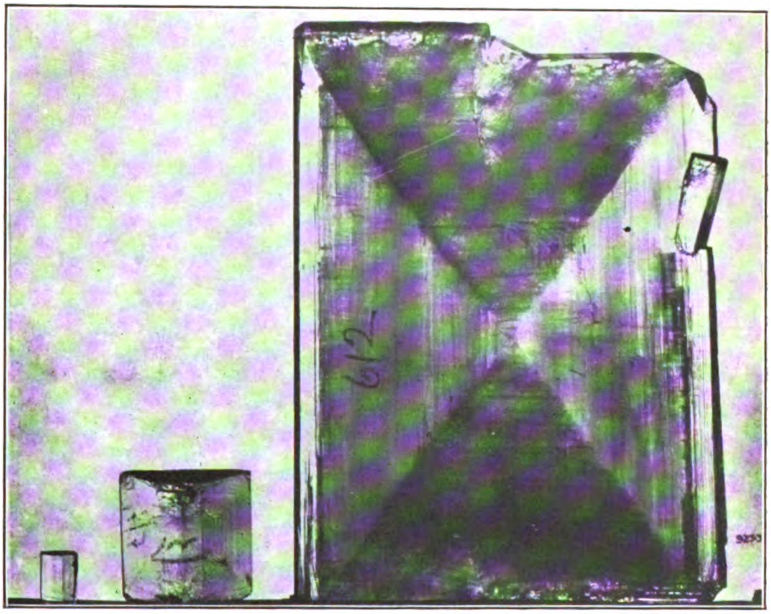


Fig. 6—Group of Rochelle Salt Crystals—Undesiccated, Desiccated and Dressed



[NICOLSON]

Fig. 7.

action at least two of these four diagonal corners a tone crystallographic pole of the crystal should be perfect and flawless, apart from the composite structure already described.

Applied Stresses

Analysis of the direction of applied stresses to the sensitive regions described has shown that, for the composite structure, a twisting couple about the principal axis excites the greatest potentials between the crystal electrodes. This may be proved in a variety of ways both for small and large piezo electric effects. One method is to prepare a crystal by dropping its poles into a pool of melted fusible metal,[21] and after the crystal has recovered from a temporary paralysis due to the heating by the metal, connections should be made between the *girdle* pole and the metal poles with high impedance receivers, which will cause sounds produced by rubbing of the metal poles to be audible. It will be found that strokes applied so as to rotate the crystal about its c axis will sound much louder in the receivers than strokes applied in other directions. Similarly the electric charge measured by twisting the crystal

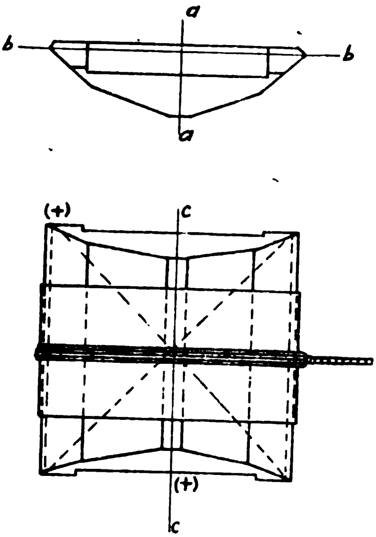


Fig. 8—Dressing of Crystal for the Girdle Orientation

is much greater than the charges produced by applying axial or diagonal forces, not only for very reduced torques and stresses but for magnitudes of stress approaching saturation in the case of the axial and diagonal forces. In the case of torsion there exists the advantage of the couple, since the force is applied at a given radius from the polar axis.

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[21] Wood's alloy fuses at 71 deg. cent. and Litowitz's at 55 deg. cent. The crystal should be introduced just before the metal sets into a thin plate.

(*a*) *The Case of a Slab Cut from a Crystal.* It may be mentioned here that a plate cut from a homogeneous[22] crystal, with its electric or *a* axis properly normal to the *c* and *b* axis, is almost insensitive to torsion, while the application of "diagonal" stresses, in accordance with Boigt's[23] crystallographic classification, does not in our practise appear to be as successful even when comparatively clear slabs of crystals are used. This may be due partly to the weakening of the structure in slicing, with consequent introduction of small flaws, and also to the difficulty of preventing in some degree the formation of the composite structure. When the uncut, whole crystal is twisted about its *c* axis so as to bend the *a* and *b* axes, component strains are developed along the principal axis as along the diagonals; but in view of the specific form of crystal and corresponding composite structure (or girdle and pyramids) presented, the resulting stresses set up in the crystal axes are very complex. Obviously the electric field is not as simple as in the case of two parallel plate electrodes.

(*b*) *Axial Compression.* On plotting the relation between electric potential and various loads applied to the composite crystal, so as to bear on the *diagonals* simultaneously, we obtain the approximately quadratic curves shown in Fig. 9. We have, accordingly, found it advantageous to apply permanent static compression and obtain thereby greatly increased effect. In view of the fact that the pressure is applied to the crystal at the limited areas of the top and bottom corners, in the basal planes, the crystallographic axis being vertical, it has been found that over a large range of size of crystal, namely between about 30 and 500 grams, the value of the applied static pressure for maximum change in slope corresponds to an absolute force of approximately 15 kg. At this point in the curve a variation of applied axial force of 1 kg. will produce in a good crystal a difference of potential of 8 volts. Beyond this point, as shown in Fig. 10[24], the curve becomes less steep. The static pressure may be applied permanently to the crystal without apparent fatigue.

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[22] A crystal will be practically isomorphic throughout when permitted to grow at a very slow and uniform rate.

[23] W. Voigt and E. Riecke, Wied. Ann., 45, 1892.

For experimental purposes the crystal is inserted in an appliance we call a "spring compressor" which compresses the crystal to the necessary degree and at the same time forms a convenient method for electrically connecting the polar electrodes, previously described. The spring compressors comprise a pair of aluminium discs which are held together by stout steel springs. These are attached by eye-rivets to the lower plate, while thumb screws tighten the springs after a crystal has been inserted. The number of turns of the thumb screw may serve conveniently as a gage of the degree of compression after calibration.

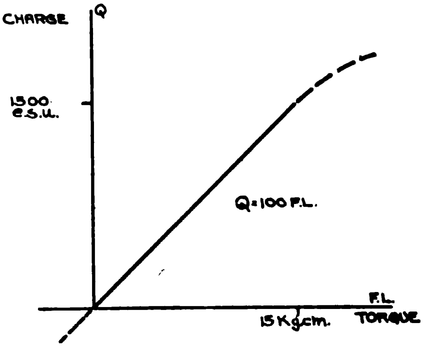

FIG. 9—AXIAL COMPRESSION APPLIED TO "HORNS" OF CRYSTAL (AVERAGE CROSS SECTION 10 CM.^{2})

Fig. 12 shows the spring compressor with the dressed crystal properly balanced within. Any part of the metal structure will readily convey jars and vibrations to the crystal. If this crystal transmitter be laid on a large sheet of paper and receivers be applied to the electrodes, it is quite easy to hear gentle rubbing of the paper and the tick of a watch—transmitted along the paper to the crystal.

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[24] The curves in Fig. 10 show slight hysteresis or fatigue near saturation values of the potential. It will be observed that the deflections at *release* of load are much greater than those for compression, probably for the reason that the action may be effected more rapidly and consequently with less loss of charge. The cycle of operations taken for obtaining the curve is as follows: a load is applied to the crystal so as to compress it; this gives a deflection on the electrometer of a value, say *b*; then the crystal is short-circuited for a moment so as to give zero reading again (shown at *c*). On releasing the load the greater deflection *d* is produced (which is in the opposite sense when the instrument is polarized, as indicated in the upper curve). An adaptation of the Riehle machine was used for large values of compression.

Torsion. As previously described in connection with the fusible metal poles melted on the crystal, it is probable that the compressed crystal receives and responds to components of forces in both axial and twisting senses. In order to analyze the relative motions of the crystal it was simple to reverse the crystal action by applying alternating potentials at different frequencies to the crystal electrodes and discover from the various modes of vibration of the crystal their relative magnitudes. A special micro-phone was applied to a crystal pole in various positions with respect to the crystallographic axis. The microphone, being in a local battery circuit operating a thermocouple, was actuated by the dilating crystal when the constant alternating potentials of various frequencies were applied. The resulting measurements showed conclusively that the crystal twisted or moved the microphone button to the greatest degree when the axis of the microphone was attached tangentially to one of the crystal poles. The motions

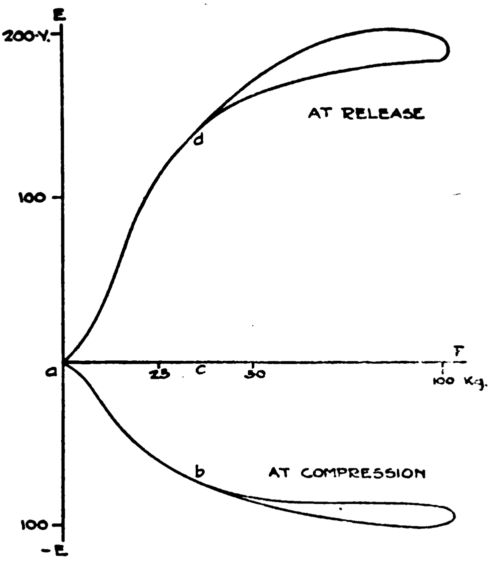

Fig. 10—Applied Axial Stress

applied to the microphone were much smaller when they were diagonal or axial in character.

The relation between piezo electric charge and torsion is linear, see Fig. 11, and is given by

$$Q = K F L$$

where K = 100 for several crystals tried
L = lever arm in cm.
F = force in kg.
Q = charge in e.s. units.

A right-hand torque determines the same electrification that is produced by subjecting the crystal to tension. If steady potentials be applied to the crystal the torsion is given, in one case, by

10^{-5} radian per volt (crystal 7 cm. long)

while expansion parallel with the crystallographic axis (c) is 2×10^{-9} cm. per cm. of length, per volt and is independent of applied pressure.

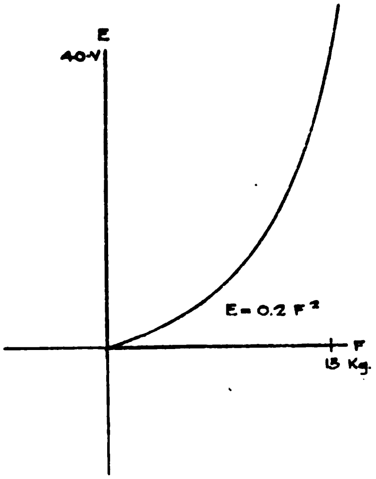

FIG. 11—ELECTRIC CHARGE OBTAINED WHEN TORSION IS APPLIED TO CRYSTAL

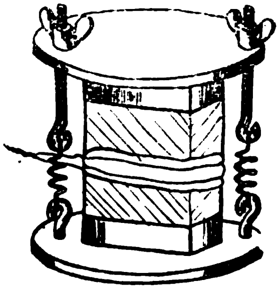

FIG. 12—ASSEMBLY

(*d*) *Alternating Effects*. If we apply rapidly alternating stresses to a crystal it becomes a generator of electrical oscillations, and we may use it as a detector of vibrations of sound, agitating it, for example, by a watch tick, a moving phonograph record, or by speech. If the crystal be tapped, an oscillogram shows that such an impact generates trains of electrical oscillations peculiar to the resonant frequencies of the crystal. Fig. 16 indicates trains of oscillations of 300 and 2000 cycles. A crystal used on a phonograph record will generate several volts, with sufficient power to operate a very large number of telephone[25] receivers.

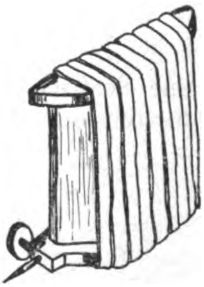

Fig. 13—Phonograph Transmitter

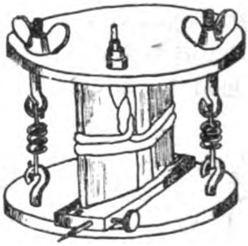

Fig. 14—Phonograph Transmitter

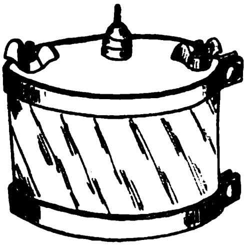

Fig. 15—Crystal Transmitter or Receiver

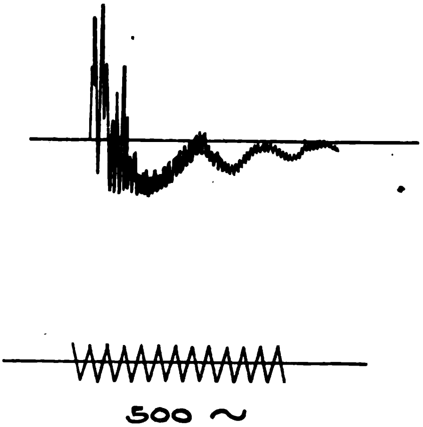

Fig. 16—Effect of Hammering a Crystal Indicating Impact Oscillations of 330 Cycles and 2000 Cycles

Applications

Again, to operate effectively, the crystal applied to the phonograph is subjected to torsional vibrations. Figs. 13 and 14 indicate the housings employed. By means of the usual needle, vibrations are imparted to a light plate under the crystal. In Fig. 13 elastic bands are shown compressing the plate against the crystal.

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[25] As many as 200 receivers of 12,000 ohms each have been operated from one crystal.

Sound Transmitter and Receiver. Since, with these composite crystals, a given force produces the greater piezo effect when it is applied in such a way as to twist the crystal about its principal axis, and conversely, an applied electrical foce producesr

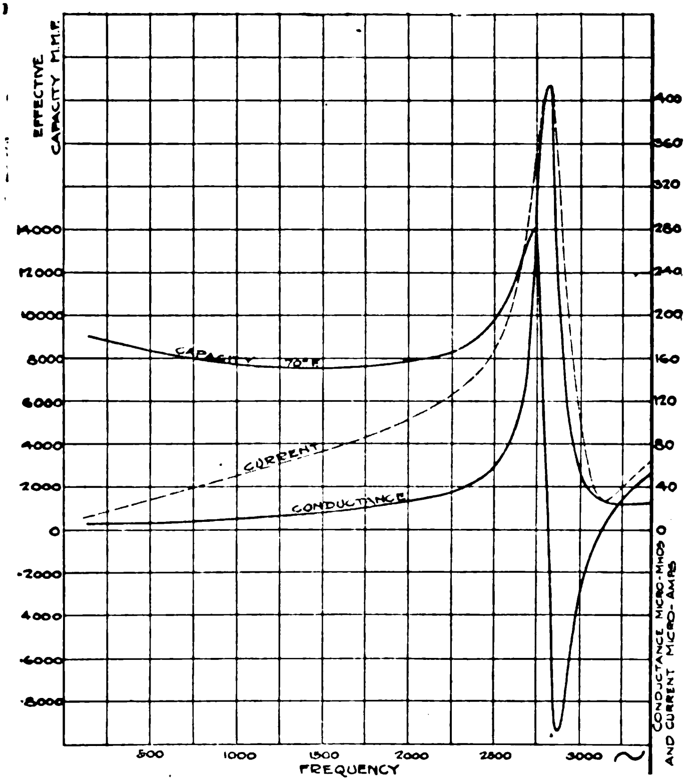

FIG. 17—CAPACITY, CURRENT AND CONDUCTANCE CURVES FOR CRYSTALS

the maximum mechanical response in the form of twisting motion, it is apparent that whether we are interested in producing electrical or mechanical results from the crystal, the diaphragms should be so attached as to make maximum use of the torsional effect.

One way is to apply a cylindrical diaphragm so as to surround the crystal, and to attach the cylinder by means of rings to the compressor plates which hold the crystal. By screwing one of the rings over one of the compressor plates the cylindrical diaphragm itself becomes twisted into diagonal corrugations stretched tightly across the crystal poles. This construction is shown in Figs. 15 and 20. The "diaphragm" should be made of a strong light material like gold beaters' skin or bond paper. When aerial tones strike the diaphragm and actuate the crystal as a transmitter, the resulting vibrations reach the crystal body through the poles and corresponding electrical oscillations are generated. Singing against the diaphragm, near resonance (the fundamental may lie between 200 and 600 cycles), will generate about 20 microamperes of current or produce 15 volts on open circuit. A clap of the hands near the transmitter will excite trains of oscillations in an oscillograph similar to the curves shown in Fig. 16. A circuit for the crystal transmitter is indicated in Fig. 18.

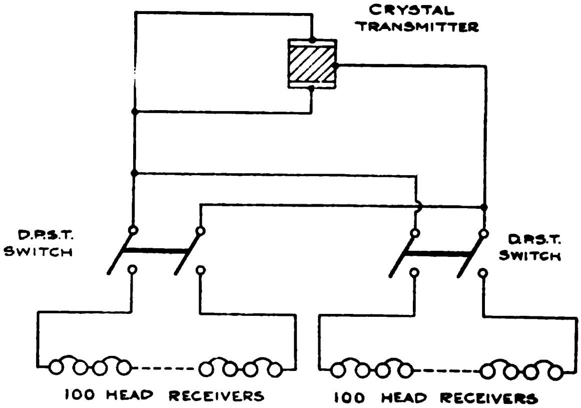

FIG. 18—CIRCUIT FOR CRYSTAL TRANSMITTER

If the crystal receiver, as described, is used with a microphone transmitter and the potential is stepped up to the crystal with a transformer as is shown in Fig. 19, very strong acoustic effects may be obtained as a "loud speaking" crystal receiver.

Crystal Transmitter and Receiver in a Line. With the aid of the vacuum tube amplifier, good transmission of speech and

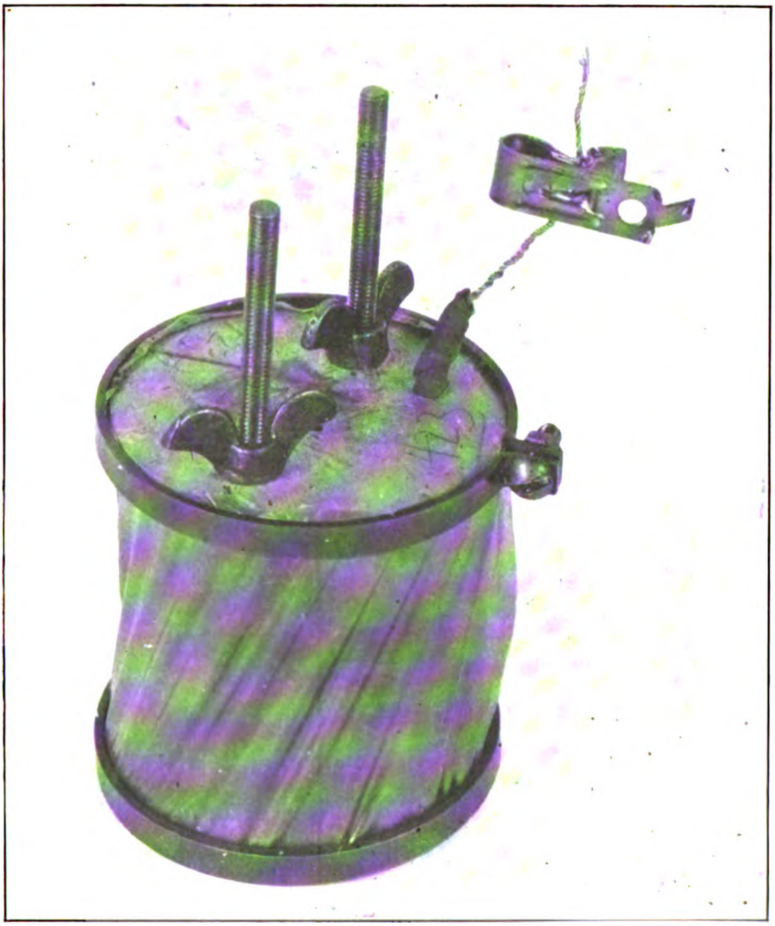

FIG. 20. [NICOLSON]

music may be obtained by using the piezo crystal at both ends of a line as sole transmitting and receiving apparatus.

Some Electrical Constants. The crystal may be considered as a leaky condenser having a shunt resistance in excess of 100 megohms. The ohmic resistance is several times greater from the analogous to the antilogous pole than it is in the reverse sense. There is however, no evidence of current rectification.

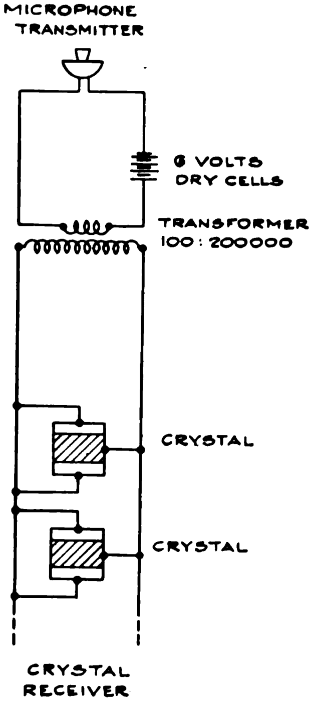

FIG. 19—CIRCUIT FOR CRYSTAL LOUD SPEAKER

The capacity varies with size and may be as great as 10^{-8} F. in a good crystal. It is usually 10^{-7} F. Its impedance at acoustic frequencies varies from 100,000 ohms to 300,000 ohms. Fig. 17 indicates that these properties depend on the frequency of the applied e. m. f. From these curves the so called "motional impedance" of the crystal may be found in the same manner as the motional impedance of an ordinary telephone receiver[26] which, as is well known, gives the resonance characteristics of the diaphragm. In the case of the crystal the dilatations reach certain maxima where the applied frequency of the alternating potentials (of constant amplitude) coincides with an elastic natural frequency of the crystal. At this frequency, the apparent capacity passes through the greatest change in value—from maximum to zero or negative values, depending on whether the crystal response, as a generator, is in phase or out of phase with the applied potentials. The impedance decreases to a minimum at resonance as indicated by the conductance curve.

CONCLUSION

Curie's law that the electric charge generated by a crystal is, for a given force, independent of the absolute dimensions, seems to be well borne out in the variety of crystals discussed in this paper. There is a best shape of crystal which we have already considered.

Very small crystals are generally less effectively rendered "composite" on account of the relative absence of the stresses during shorter growing periods. Hence they are generally less efficient when mounted as described. On the other hand, properly articulated crystals may be grown far larger than is necessary for effective operation. For example, Fig. 7 shows an illustration of a crystal weighing 910 grams. It is difficult however, to prevent cracks and flaws taking place before the large crystal has been effectively cured and hardened.

It has been noticed that the crystals improve with time, particularly when they are first made. Moreover, when they are paralyzed by being baked at too high a temperature they slowly recover. Drying out is probably one cause of this improvement and also realignment or recrystallization of disturbed portions of the crystal molecules.

It may be said that the crystals, after several months' use, or non-use, reach a very steady operating condition in which their activity seems to be permanent, especially for alternating effects where weather conditions have negligible action on sensitive apparatus associated with the crystal. As regards general efficiency and comparison with known apparatus like the carbon transmitter and the electromagnetic receiver, it should be said that the microphone is more sensitive than the crystal transmitter. The microphone with its associated local battery gives out more energy than it receives and hence constitutes an amplifier; while the crystal at present translates only that portion of the energy applied to it which affects its mechanically sensitive regions.

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[26] A. E. Kennelly, Proc. Amer. Acad. Sc., 1912A p. 114.

The efficiency of the crystal receiver compares favorably with the electromagnetic receiver for equivalent resonance conditions. It is not improbable that other crystals of organic constitution, *i. e.*, of *molecular* asymmetry, may be found whose piezo electric activity may exceed that of Rochelle salt. So far very little is known about the electrical and mechanical orientations set up in other crystals capable of developing the composite structure described in this paper.

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APPLICABILITY OF AUTOMATIC SWITCHING TO ALL CLASSES OF TELEPHONE SERVICE

BY ARTHUR BESSEY SMITH

Abstract of Paper

This paper is an attempt to place before engineers general information in regard to automatic telephone switching.

The subscriber's requirements are independent of the means used to satisfy them. Automatic switching is uniformly fast and involves reduced mental stress to the user because the passing of the number is positive and waiting time is reduced to the minimum. Viewed by the owner the apparatus has longer life, the service is very acceptable to the public, and but a tithe of the female employees are used.

Automatic switching apparatus has increased greatly in margin of safety. Much progress has been made toward standardization of form and toward best methods of maintenance. A few changes in structure are described and data given to show margins of safety in operation. Present practise regarding party lines and measured service (cash and credit) is stated briefly. The durability of automatic equipment is illustrated by the fact that plants have not yet worn out. Maintenance routines are essential to successful operation. Girls do routing testing with marked success.

Rural telephone lines present problems which have been solved in several ways, influenced by the greater number of telephones per line, the conditions of signalling subscribers, and the inferior insulation often encountered. Code ringing can be retained. Rural automatic service is only a little inferior to city automatic service.

The community automatic exchange serves a small group of subscribers, either isolated or part of a telephone network. The rotary line switch is used because it is simple, reliable, quick-acting, and provides 25 trunks. Eight variable factors in exchange design are presented with a discussion of each.

Toll switching in an automatic exchange gives the toll operator direct dialing to the subscriber, complete control over his line, and periodic ringing. The toll network has also been improved by applying automatic switches to intermediate points, so that the originating toll operator can set up the complete connection herself. The experience of the past twelve years shows that this increases the business-carrying capacity of toll lines at least 50 per cent to 100 per cent. A variety of schemes are available.

The automatic switching of telephone lines is adaptable to all classes of telephone service and offers a flexible means of solving problems.

ENGINEERS and others interested in the building of telephone plants often ask the question, "Will the automatic telephone system meet the needs of this particular case?

Though it may be successful elsewhere, perhaps it can not be adapted to suit the peculiar conditions found here?" To answer such questions as this is the motive underlying the preparation of this paper. Though the writer can not cover every conceivable condition, he believes that it is possible to place on record many facts which will be useful to those who have to do with automatic telephony.

The approach to automatic telephony must be made with an open mind. A highly critical attitude prevents one from appreciating such facts as are observed. The writer formerly regarded automatic switching as desirable but somewhat inflexible. His experience and observation have led him to revise his opinion. Automatic switching can be adapted to meet every need of public and private telephone service, and will do it with marked advantages.

Three kinds of service have already been discussed by the Institute. In 1908, Mr. W. Lee Campbell presented a paper entitled "A Study of Multi-Office Automatic Switchboard Telephone Systems," and again in 1910 a paper on "A Modern Automatic Telephone Apparatus." In 1912 Mr. Gerald Deakin presented "Private Automatic Exchanges in Apartment Houses." In 1910 the writer discussed "The Automatic Telephone in Relation to City Service," including suburban traffic.

The classes of telephone service which are to be treated in this paper are as follows:

The single office exchange, the basis of discussion.
Rural lines.
The Community exchange.
Toll or county line network.
Long distance toll lines.
The comprehensive system, including all kinds of service.

General Considerations

Before taking up the details of various classes of service, it is well to call attention to a few general factors, such as the requirements of subscribers and of the owners of telephone exchanges and of the characteristics of automatic equipment most generally used.

Subscriber's Requirements. The subscriber's requirements must be stated in terms which are independent of apparatus or methods. Much error will be avoided if we divest our minds of conditions imposed by any one means of rendering service.

The subscriber requires, without unnecessary delay, without undue stress on himself, to be connected to the telephone which he desires (and to no other), to talk to the called subscriber with ease and without interruption or eavesdropping, and to have this service available continuously. Stated concisely the requirements are

1. Speed of connection (and disconnection)
2. Ease of obtaining connection (and disconnection).
3. Accuracy of connection.
4. Voice transmission.
5. Secrecy.
6. Continuous service.

Repeated tests of a formal nature and the general experience of users of both manual and automatic equipment have settled conclusively that the latter is very much superior to the former in speed of connection. But uniformity has value as well as actual speed itself. The average automatic connection is completed in from 4 to 6 seconds, regardless of the time of day or the conditions of business. Subscribers judge the speed of a service somewhat by the average speed, but more especially by the occasions on which they suffer delay. The fact that automatic service is *uniformly* fast, greatly increases its value to the user.

The speed of connection is greatly influenced by previous conditions. If a connection exists, and one of the two subscribers desires immediately to make another call, it can be done most quickly with the automatic telephone. Hanging the receiver upon the hook for one second clears the line and permits the immediate originating of another call. A large amount of telephone business may be transacted in a short time by automatic equipment.

The stress laid upon the subscriber in originating a telephone call is mental rather than physical: It may be divided into two causes, the waiting periods and the transmission of the number of the called telephone.

With the automatic telephone, waiting is reduced to a very low factor. Things begin to happen the instant the receiver is removed from the hook. The subscriber has something to do from the very start, and when he gets through doing it, the connection has been completed and the bell of the called telephone is beginning to ring. The only waiting period is the time of ringing. Even during this time the subscriber's mind is more or less occupied by the sound of the ringing, which he can hear. Or if the called line is busy, he is immediately informed of that fact by the unmistakable "busy tone." Not only does the automatic telephone greatly reduce the waiting time, but to a certain extent it conceals the total time required.

The transmission of a directory number by the dial of the calling device produces less strain on the user than the effective transmission of the same number by the voice. It requires a distinct effort to enunciate the syllables of the various digits clearly enough to prevent mistakes. On the contrary, the sending of the number by a calling device is easy and involves no appreciable stress. For each digit, the finger is inserted in the proper hole, the dial rotated to the finger stop and let go free. The mechanical definiteness of number transmission makes automatic calling easy.

When a subscriber desires to talk to a certain telephone, he wants that telephone and no other. It is a distinct advantage to him to know that he is getting exactly that number. This is afforded by automatic switches to a much greater degree than by human beings. Automatic switches, as now made, have a large factor of safety against error. They are designed and constructed so as to be as permanent in structure as modern materials will permit. Each part is separately adjusted within limits which impose rigorous conditions. The final assembly is again tested under conditions far more severe than those found in service. The chance of getting a wrong number by fault of the apparatus is so small that it can be entirely neglected. This fact is soon discovered by habitual users.

There is nothing inherent to automatic telephone equipment to prevent the very best voice transmission.

Much has been said for and against the value of the secrecy of the automatic telephone. It still remains true that users of the system recognize and value this property. It has been said that the operator at a manual switchboard is too busy to listen to conversations—this is true only during peak loads. Some manual switchboards have "automatic listening", which excludes the operator as soon as her work is done—this prevents her from giving the connection any supervision, and defeats part of the fancied advantage of having a human intermediary. It has been said that the mechanicians employed in automatic switchrooms constitute as much menace to secrecy as the manual operator. This is not so because the man's work is laid out according to a fixed routine. He is not permitted to run about the room according to the dictates of his own judgment. What he shall do, when and how he shall do it are laid out on a schedule. His day is uniformly filled, without peak loads. Secrecy is even more evident in the private automatic exchange, where the personal interest between people is stronger and the danger of eavesdropping greater. These switchboards are without constant attendance; they run for long periods with adjustment or repair.

Absolutely continuous telephone service has come to be the standard. Continuous service is given. But it is well known that manual night service is not as prompt or as good as day service. Automatic switches work just as promptly and accurately at midnight as at noon. The public deserve as good night service as day service, for often the need of a single night call may be more acute than that of many day calls.

Requirements of Operating Company. The requirements of the operating company are determined by viewing the telephone exchange as an investment. It must yield an adequate income to the stockholders. It must be a permanent business. To be stable means that it must render satisfactory service to the subscriber and not be too difficult to manage. These requirements are not all that there are, but they have an important bearing on the business.

1. Earning ability of investment.
2. Permanence of investment.
3. Satisfactory service to subscriber.
4. Ease of management.

Telephone exchanges must pay their way. If automatic exchanges do not pay, there would not be any of them left in existence today, for this movement is twenty-seven years old.

Five exchanges, formerly manual, were converted to automatic. They ranged in size from 2300 lines and 4400 telephones to 38,000 lines and 44,000 telephones. The totals for the five were 47,000 lines and 65,000 telephones. The comparison of expenses is as follows:

	MANUAL	AUTOMATIC
Total operating and maintenance expense per year	$552,600.00	$136,800.00
Average per line per year	11.77	2.92
Average per telephone per year	8.50	2.11

At least ten of the exchanges in the United States are from fourteen to sixteen years old. Based upon the record of the existing plants and the improvements in use today, new exchanges are built every year.

The permanence of an investment depends upon the rapidity with which the equipment is destroyed, the danger of its being rendered obsolete by reason of advances in the art, and the attitude of that court of last appeal, public support.

An apparatus to be a permanent investment as to depreciation, must be capable of being kept in first class running order by ordinary maintenance, without stretching the meaning of the word.

Surely any equipment which in ten years becomes so badly worn that it can not give adequate service, or that the repairs are considered excessive, so that it must be thrown out bodily, can not be considered as being very permanent.

The life of an automatic switchboard is not known. Numerous switchboards now in operation were installed more than 15 years ago, have been in constant service since then, and are still giving the same grade of service. All the moving parts are subject to no other forces than those of the switch itself. Those forces are adequate and are always properly directed every time they act. Those parts which wear are capable of easy renewal and are taken care of by ordinary maintenance.

Although the structure of automatic telephone apparatus has been changing through a considerable period of years, most of the changes are beyond the observance of the subscriber. The oldest equipment gives nearly as quick and satisfactory service as the latest. The telephone instrument has been improved in appearance, but the old ones are still giving a service comparable to that rendered by the new. For this reason, there is little obsolescence to automatic equipment. This being true of old apparatus, it is much more true of the latest apparatus on the market.

Public support is a factor which must receive adequate consideration. Though in the past some have ignored it, the results have been anything but pleasant and have reacted unfavorably upon those who did the wrong. Any business to be classed as permanent, must have with it public support, and the more of it the better.

The public recognizes and supports the company which gives its patrons the benefits of improved service obtained from new devices. They may not clamor for something which is rather hazy or of which they do not know. But let them once experience the benefits due to the new device and their support is assured.

It is a matter of record that the great mass of the public who have habitually used both services, prefer automatic to manual. It is not a doubtful majority—the preference is as nearly unanimous as can be found. In 1911 the Automatic Electric Company sent out 3000 letters to subscribers who had been using both manual and automatic service, and 1869 replies were received of which 91.7 per cent unqualifiedly preferred automatic service. Since then others have investigated the subject with varying results, but always with the ratio in the same direction and very positive.

Other things being equal, people prefer an investment which is easy to manage. One which presents troublesome questions which seem never to come to an end is shunned, because one can never tell when something may upset the financial condition. Any factor which makes the business easier to manage, renders the investment more attractive.

The manual telephone operator is the source of exceedingly vexatious problems. She requires careful handling, adequate accessory conditions, and although her pay is rising from year to year she does not stay long in the business. At best, hers is a nerve trying occupation, and it is no wonder that conditions are as they are. They are inherent.

The automatic telephone switchboard removes about 90 per cent of the female help in central offices. The increase in male help is only about 9 per cent. The duties of the former human operators are performed by machines which require no "managing."

EQUIPMENT CHARACTERISTICS

Automatic apparatus of various kinds has been described so often that a general explanation is unnecessary. The type best known has been the subject of Institute papers, as well as of a few books.

Factor of safety is a thing of great importance. Upon it depend the maintenance expense and the dependability of the service rendered to the public. This is the principle which guided the development of automatic switching. Seemingly small details exert great influence upon the performance of apparatus. Some factors do not impress the casual observer, yet they have great influence upon results.

A brief presentation of some of the improvements which have been made in recent years will bring the record of the subject up to date. It concerns chiefly the redesign of parts of the apparatus and the standardization of the assembly, adjustment, and mode of maintenance.

The automatic switch, Fig. 1, presents a new general appearance. The relays are mounted above, the magnet mechanism in the middle, and the banks and wipers below. The relays and magnets are protected by a cover individual to each switch.

The material of the switch frame has been changed from die-cast metal to cast iron, heavily zinc plated. The die-cast frame was subject to warping. It necessitated rather frequent re-adjustment of the mechanisms mounted on it and sometimes even the chipping down of a lug which interfered with the movement of the wiper-shaft. The cast iron frame is rigid and unchanging. Apparatus mounted on it requires no attention from this cause.

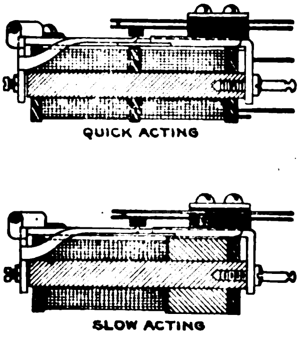


FIG. 2—HORIZONTAL AUTOMATIC RELAYS

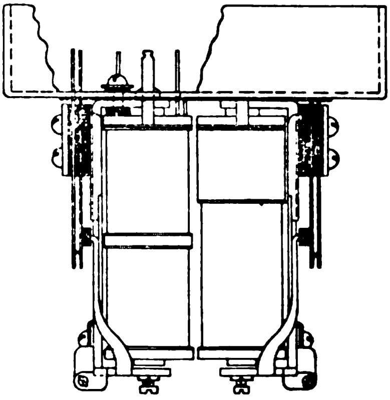


FIG. 3—AUTOMATIC RELAY MOUNTING (TOP VIEW)

The sideswitch has been abolished on nearly all switches and its work performed by relays. The sideswitch as made was the source of considerable trouble due chiefly to the wiper friction. Its elimination has greatly increased the certainty of action of the switch as a whole.

The relay has been completely redesigned (Fig. 2). The pin-pivot has replaced the point-pivot, the insulation between contact springs made permanent, and each relay rendered mechanically independent of all other relays.

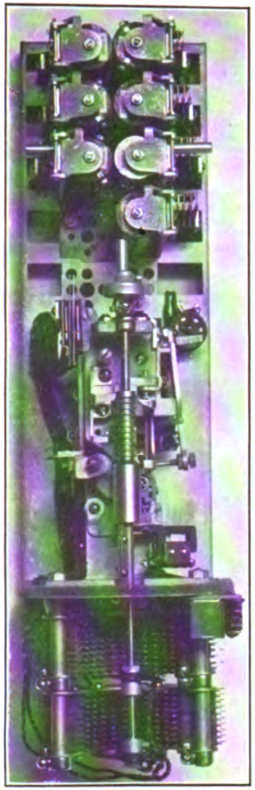


FIG. 1A—CONNECTOR SWITCH (FRONT VIEW)

[SMITH]

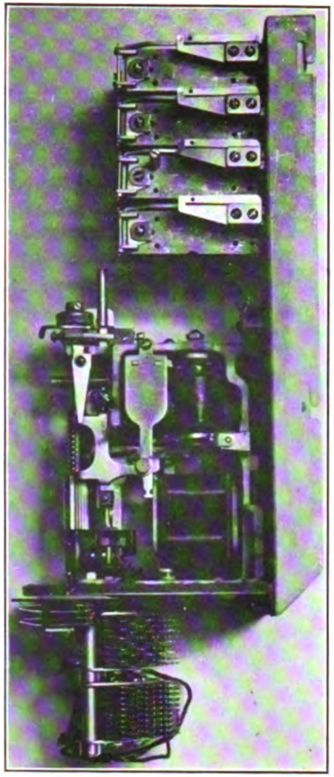


FIG. 1B—CONNECTOR SWITCH (RIGHT VIEW)

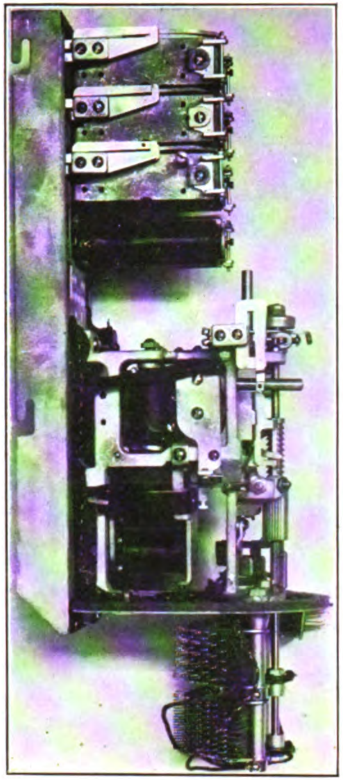


FIG. 1C—CONNECTOR SWITCH (LEFT VIEW)

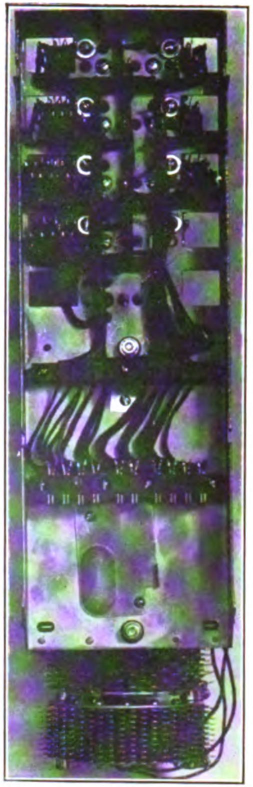


FIG. 1D—CONNECTOR SWITCH (REAR VIEW UNCOVERED)

The point-pivot, when adjusted without play or bind was as fine a pivot as could be made. But it was desired to have a pivot which would need no adjusting at all. The plain pin pivot has just enough play to make the armature work freely, and the wear is inappreciable. The point pivot is retained on the line relay of the plunger line switch, where the conditions are not severe.

The relay contact springs are insulated by phenol-fibre, which is a good insulator and very constant. Each assembly of springs is aged by heat treatment, so that it is practically one solid mass. Looseness and uncertainty of spring action have been practically wiped out.

The relays are mounted individually on a base plate Fig. 3. This base plate has openings through which the relay terminals (for coils and springs) extend to the rear. There the wiring is placed, connecting the relays together in a compact but accessible place. A plate covers the wiring so that none of the wiring on this part of the switch is exposed. The few wires which feed the magnets and wipers pass through a single hole in the base plate. The base plate carries also the switch frame, in which the vertical, rotary, and release magnets are mounted.

The adjustment of an automatic switch may be divided into two parts, the relay adjustment and the adjustment of the motor magnets. Every relay is adjusted to a definite armature-stroke with a fixed residual airgap. The amount of contact that each spring makes with its mate is likewise fixed. These distances are measured with thickness gauges placed between the armature and the pole of the magnet.

The contact springs of each relay are given a tension which is measured in terms of the operating and non-operating currents. Thus the spring tension is kept within limits.

The motor magnets (vertical, rotary, and release) are adjusted in a definite sequence to the proper relations to the wiper-shaft. These relations are also expressed in distances, most of them measured by thickness gages.

The final performance of the completed switch is tested by being operated over a line under conditions worse than any imposed by commercial use. The calling device delivers impulses at 14 cycles per second with an impulse ratio of 61 per cent (circuit opened 0.61 of total impulse period.) One test employes a line of zero loop resistance with a 20,000 ohm leak across it. The other test employs a 1200 ohm line without leakage.

The spring tension of the motor magnet armature is adjusted so that perfect operation is secured under these two extremes of line conditions, with the battery voltage between 46 and 49 volts.

The control of automatic switches over the subscriber line is a telegraph problem. The elements involved Fig. 4 are the line circuit, the release relay circuit, the motor magnet circuit and the release magnet circuit. All but the line circuit are wholly within the central office where the conditions are constant. Each element contributes its share toward fixing the line characteristics which are necessary for operating a switch.

The normal operation is as follows: The calling device springs (CD) are opened and closed as many times as there are units in the digit being transmitted. The line relay (LR) follows these impulses. The release relay, (Rel-Ry) having a copper collar remains energized during the series. The series relay pulls up the first time the line relay falls back and remains energized during the series of pulsations to which the magnet (VM) responds by moving the wiper shaft the required number of steps. At the end of the group of impulses, the line relay comes to rest energized, the series relay falls back and causes the local circuit to be changed to suit the next action.

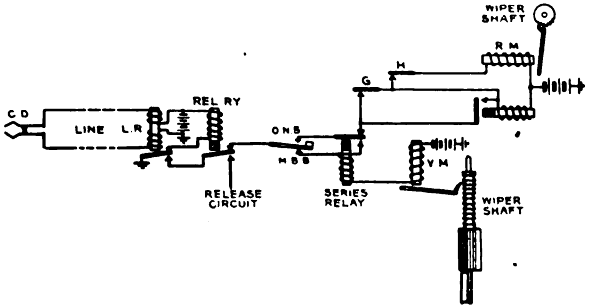


Fig. 4—Controlling Circuit for Automatic Switchboard

The period of an impulse Fig. 5 is the time from the opening of the line to the next opening of the line. It includes a "break" and a "make." The upper line represents the time that the line current is flowing. It is shown as broken three times, as in sending the digit "3." Each opening of the line produces one pulsation to the magnet. This is represented by a line just below the break in the line current. Owing to the delay of the line relay in obeying the current, there is a little time-lag at the beginning and at the end of each pulsation.

The impulse ratio is the ratio of the time that the line is opened to the total period of the impulse. Applied to the magnet, it is the ratio of the time of current flow to the total period of the impulse. Formerly a fifty per cent (0.5) impulse was used. It has been found that a longer opening of the line circuit gives greater certainty to the selection, so that sixty-one per cent (0.61) is now used. The reasons are discussed below.

The release relay must be held energized continuously, because when it falls back it will cause the switch to release. The greatest break in current which the release relay can stand without letting go is about 77 per cent. (For a group of 10 impulses at 10 per second.) At the beginning of a group of impulses, the release relay is fully energized. While the line relay armature is vibrating, the release relay is kept energized by pulsations fed to it, one pulsation each time the line relay pulls up. If these pulsations are short, the magnetism will not be fully restored each time but will gradually run down. There is always enough magnetism remaining to hold the armature to the end of ten impulses. The aging of a slow acting relay (equipped with a copper collar) always tends to make it hold better.

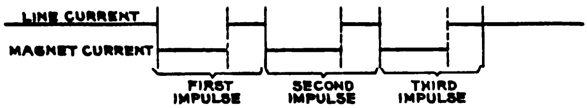


Fig. 5—Impulses

The series relay must also remain energized as long as pulsations are being sent to the motor magnet. The shortest pulsation which it can have is about 28 per cent for ten pulsations at 10 per second. The conditions which supply long pulsations to the series relay, give short ones to the release relay. But the short pulsations which each can endure give a large range through which the ratio can vary without causing either relay to cease to function properly.

The vertical magnet requires at least a 27 per cent pulsation and not more than 86 per cent for satisfactory operation under the same conditions. Being in series with the series relay, it gets the same impulse ratio. Since the magnet has considerable work to perform, it can stand a very high ratio.

The rotary magnet of a connector can stand a variation of impulse ratio from 30 per cent to 95 per cent.

The total performance of the automatic switch is judged from the standpoint of the subscriber's line. Ordinarily a switch is adjusted to work over lines of varying length. This is because any telephone may use almost any switch. Sometimes a switch is to be used on one line or trunk only; in this case the line relay can be adjusted to operate on a 2500- or 3000-ohm loop. When adjusted for such a loop it would not work well on a low resistance loop (300 ohms and under.) Loop resistance of the subscriber's line does not include the telephone instrument because in an automatic telephone the talking apparatus is cut out during the dialing period.

If the subscriber line is of zero length with no leakance or capacitance, the impulse ratio may vary from 38 per cent to 71 per cent without causing the switch to fail.

The effect of simple line resistance is to lengthen the pulsation delivered to the motor magnet, and shorten the pulsation to the release relay. This results in weakening the release relay so that it may start to fall back near the end of a ten impulse digit and if the line resistance be excessive may even cause premature release. If the loop is 500 ohms, the impulse ratio may vary from 36 per cent to 72 per cent without causing the switch to fail. If the loop is 1000 ohms, the limits are 35 per cent and 68 per cent. The margin for safety is ample.

The practical safe limit for a subscriber's line is a loop resistance of 1000 ohms. This is a greater resistance than is necessary for good common battery transmission, so that any loop which is low enough in resistance for good transmission is good enough for automatic dialing.

The effect of line leakage is to cause the line relay to be slow to fall away and prompt to pull up. This gives the motor magnet and its series relay a shorter pulsation, so that there is less power available to move the switch and a greater likelihood of the series relay not remaining energized throughout the group of pulsations. The practical limit of leakance is about 50,000 ohms for the subscriber's line, measured between wires or from either wire to earth. Since the switches are adjusted to operate perfectly with a leak of 20,000 ohms across the line, the factor of safety is ample.

Distributed capacitance such as found in telephone cable exerts no bad effect upon dialing. A capacitance between the two conductors has a tendency to delay the relay in falling back, and thus to shorten the pulsation delivered to the motor magnet. This partly neutralizes the effect of line resistance. In fact, the capacitance may be increased to seven microfarads without causing the automatic switch to fail.

Lumped capacitance, as found in telephone instruments on a party line, affects the dialing. It is more correct to say that it is the inductance of the bell in connection with the capacitance of the condenser that influences the signals. For this reason the capacitance of condensers used with harmonic bells (5 bells on one party line) is made 0.7 microfarad. With this value at least two more bells could be used without causing any failure of dialing.

In general, line faults have the same effect upon an automatic switchboard that they have upon a manual switchboard. The chief effects are compared in the table following.

	Manual	*Automatic*
Open.	No calls, no indication	No calls, no indication
+ *L* grd.	Line noisy, conversation poor	Line noisy, conversation poor Dialing bad, sometimes impossible
— *L* grd.	Permanent signal	Permanent signal
sht. ckt.	Permanent signal	Permanent signal
	Crosses between lines.	
+ *L* and + *L*	Cross talk	Cross talk, a second trunk occupied but no trouble
— *L* and — *L*	Cross talk, two line signals show when one calls	Cross talk, a second trunk is occupied when one calls
+ *L* and — *L*	Permanent signal on one line	Permanent signal on one line

A rotary line switch has been produced which beside giving access to 25 trunks possesses other advantages. It was the equipment furnished by the Automatic Electric Company for the Automatic Telephone Exchange at Orleans, France. Its chief use in America is in the Community Automatic Exchange. It will be described in this paper under that subject.

Periodic ringing is the accepted practise, on both individual and party lines. If the subscriber removes the receiver from the hook, the ringing current is cut off at once, even if it occurs during a time of ringing. The cut-off is quick enough to be complete before the receiver reaches the ear.

Party lines are segregated and served by party line boards, one hundred lines per board.

The preferred practise is to provide a party line board with four or five groups of connectors, each group being supplied with a different frequency of ringing current. Each subscriber line is multipled to all these groups of connectors. The hundreds digit of the call number selects the group of connectors and therefore fixes the frequency which shall be used. The last two digits control the vertical and rotary motions of the chosen connector as usual. Any group of connectors can equally well connect to the desired line, but the bell which rings depends upon which group of connectors is used.

An alternative method is to have but one group of connectors per hundred lines and to equip each connector with a frequency selecting device which is operated by the last digit of the call number. It makes each call number one digit longer, but is somewhat cheaper as to initial cost.

Telephone service for intermittent users (other than regular subscribers) is usually furnished by stations equipped with some form of coin collecting box. For local service, the rate is displayed near or on the telephone instrument together with directions for its use. For toll or long distance service, the user must call for the toll board to receive supervision and information.

The automatic telephone has been successfully equipped with "nickel-first" and "nickel-last" coin-boxes. With the former, the deposited coin is held until the called station answers, then a reversal of current operates a polarized relay in the coin-box which collects the money. With the latter, the user dials the number as usual, the answering of the called station reverses the battery current which operates the polarized relay in the coin box, the latter short circuits the transmitter and shunts the receiver enough to prevent its use as a transmitter, but still permits hearing that the called station has answered. Depositing the coin clears the transmitter and receiver.

A credit meter is also in use, which records the number of completed connections. It may be attached to the instrument and worked with a push-button (instead of a coin) or may be located apart from the telephone on the subscriber's premises and require no act of the subscriber. An older type of meter is designed to be located in the central office.

If the pay station be used to call a free local number, no current reversal will take place. All free lines are connected to a group of connectors which do not reverse the current when the called station answers.

When the user of a pay station desires an out-of-town connection, he dials the toll recording desk as any local subscriber would do. When the connection is ready, the line operator calls the pay station automatically, requests the payment, and is by sound notified of the deposit of the coins as is the case in manual practise.

Durability. The durability of automatic equipment is attested by the performance of the older plants. A group of ten exchanges scattered over the Union, were installed from May 1903 to December 1904. These exchanges are still (1919) in operation. Their original joint capacity of 19,476 lines has grown to more than 104,000 lines. The original equipment is still in use. During about fifteen years of service, the regular maintenance has been able to keep the apparatus in good shape. Today the cost of maintenance material for the switchboard per line per year is from 7 to 9.5 cents, and for the calling device 2 cents per year.

Maintenance. The proper maintenance of any machine requires that it shall be prevented from deteriorating. It is cheaper from every reasonable standpoint to keep it in good working order than to neglect it until its condition is so bad that it has adversely affected service. Each function should be tested at such intervals as have been found necessary to give good service.

In a public exchange the routines involve inspections occurring daily, weekly, monthly, quarterly, twice a year and yearly. The daily, weekly and monthly routines are merely precautionary inspections, they are not adjustments.

The daily routine includes a rapid inspection of the functions of selectors. Once a week there is a rapid inspection of the line switchboards and of the functions of connector switches. Once a month the alignment of line switch plungers is examined, and the dust cleaned off the switch covers, tops of bays, etc.

Every three months the selector trunks are tested (continuity of bank and terminal wiring, particularly of infrequently used or overflow trunks and switches), wiper cords are examined and replaced if necessary, master banks and wipers are cleaned and inspected, and alarm relays are inspected and adjusted.

Twice a year the contact springs of relays and other devices are inspected for proper movement and tension and brought to standard. The switches are tested for operation under extreme line conditions. Switch shafts and master switches are cleaned and oiled. Banks are cleaned and wipers adjusted and replaced if worn. A rapid inspection is given to the rotary motion of selectors. All equipment is tested for freedom from grounds on frames and supports.

Once a year everything is checked up for conformity to standard and brought to standard. This includes the ratchet mechanism (vertical, rotary, and release) of each selector and connector, the repeaters, the line switch plunger alignment and its bank contacts and the cut-off relays.

The maintenance of an automatic exchange requires the attendance of persons who know what to do and when to do it. The average mentality required is not higher than for a manual plant of the same size.

A single office exchange having 2300 lines and 5500 subscribers telephones requires approximately the following force for maintaining the central office equipment.

One switchman.
One service clerk.
One line tester.
One information and complaint clerk.
One night man (answers toll board in addition.)

A two-office plant having 5400 lines and 10,000 telephones requires the following central office force.

One service chief.
One switchman.
Two apprentices.
Two service clerks.
One tester.
Two information clerks.
Two assistant clerks (also take care of complaints.)

The telephones can be increased to 13,900 without adding to the central office force. A service chief has charge of the switch room and does work on equipment. A switchman makes adjustments and repairs. An apprentice performs routine tests, supervises signals, and answers telephone calls to the switch room; an apprentice may be in training to become a switchman. A service clerk is a girl who performs the same duties as an apprentice. A tester makes tests on local and long distance lines; and in a small plant may act as despatcher, routing the outside troublemen. The duties of information clerk are the same as in a manual plant. The employment of girls to perform routine tests has become a factor in exchange maintenance. They learn easily, are quick and careful in their work, and are proving very satisfactory.

Rural Telephone Lines

Telephone service on rural lines differs from that in cities and towns in that dwellings are much farther apart, there is usually no common center (except the nearest town) and greater dependence is placed on the telephone.

The requirements of the subscriber are low rental, dependability of service, and the ability to make many calls to those in his own neighborhood. On the other hand, the rural subscriber is usually willing to do more than his city brother. He will gladly push buttons, turn cranks, and do anything else if necessary to get good service.

The operating company must have cheap but substantial lines, with as low an upkeep as possible, and a simple telephone requiring little maintenance.

Manual rural lines are usually operated with local battery transmission. Automatic rural party lines are also in use with local battery and with success. But a special weak current common battery transmitter has been developed which gives as good transmission on a 400 ohm loop as an ordinary transmitter does on zero loop. This has to a large extent made it possible to operate rural lines with common battery, with evident economies.

Equipment Characteristics

The characteristics of the equipment which handles rural lines depend upon the telephone instruments, the method of operation which is desired, and the line conditions which are necessary in this class of business. Insulation can not be maintained at as high a figure as is possible in the city. Line resistance must greatly exceed the usual values. Many more telephones must be put on a single line than is necessary in town. These facts require changes in the apparatus.

Because of the number of bells and condensers (sometimes ten) bridged across the line and the lower insulation which is at times unavoidable, the control circuit and apparatus must have a greater factor of safety than is usual. To secure this a repeater is interposed between the rural line and the regular exchange apparatus.

This repeater has two line relays, Fig. 6, one in each battery lead. The impulsing is done with the relay which is connected to the positive grounded battery terminal. Also, during the time that impulses are coming in, the impedance of the negative line relay is greatly lowered. These two provisions greatly increase the reliability of the selection.

It frequently occurs that rural lines produce so much traffic that it overloads the group of first selectors belonging to the line-switch board (hundred line group). This is relieved either by subdividing the line switches into smaller groups, or by providing each rural line with its own first selector instead of a line switch; in this case the selector performs the functions of repeater as well as of selector. The relative cost of the two plans varies with conditions.

One condition incident to placing so many telephones upon one line is the chance of interference of one subscriber with the dialing of another. This is obviated by providing each telephone with a hook stop. It permits the hook to rise part way, only far enough to connect the receiver across the line (in series with a 2 microfarad condenser.) This allows the subscriber to listen without interfering with dialing which may be going on. If the line is free, the subscriber presses the hook stop; the lever then rises to the full extent of its stroke, connecting up the calling device and completing the talking circuit. Beside preventing interference with dialing, this device permits the rural subscriber to listen as much as he desires—a habit which is firmly established and warmly defended.

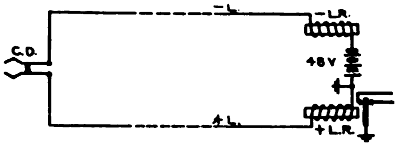


FIG. 6—RURAL LINE CONTROLLING CIRCUIT

The signalling can be either selective or code ringing. The latter is very largely employed by manual exchanges, is understood by the subscribers, and seems to be satisfactory. Selective signalling is better in some respects, but the choice properly lies with those who are closely in touch with local conditions.

To ring ten bells selectively, five bells are bridged from each line wire to earth and rung with five frequencies. Two systems of frequencies are in use. The "multiple harmonic system" employes 16.7, 25, 33.3, 50 and 66.7 cycles per second. The "non-multiple harmonic system" uses the frequencies 20, 30, 42, 54, and 66 cycles per second. This duplication resulted from the historical development of two systems, and there are many installations of both in use today. It is to be hoped that one of the two may be retained as the better, and the manufacture of the other discontinued.

Code ringing permits all the bells to be alike and to be bridged across the line. In order not to interfere with dialing, the bells are wound to 3600 ohms (*approx. 5000* ohms impedance at 10 cycles per second) and the condensers limited to 0.3 microfarad capacitance. Signals may be made of combinations of long and short rings or of two groups of short rings separated by a pause.

Rural lines are served by a line-switch board set aside for this purpose. The special apparatus required is localized to this part of the equipment. If the signalling is selective, each connector has mounted on it a minor switch which picks out the frequency to be used. If code ringing is used, each connector has a code selector and a code switch. The latter groups the code signals, the former picks out the desired signal. The code switch is a single motion (rotary) switch with a 25-point bank. The code selector is the same in form and size as a first or second selector. They involve mechanisms which have been established by experience.

In general, reverting calls are handled by providing special switches leading to reverting call connectors. Each of these connectors is equipped much as a regular rural connector is equipped, but is wired so as to ring back on the originating line. If selective ringing is used, the reverting call connector will send out alternately the frequency of the originating station and of the called station. The total period of repetition is 4 or 5 seconds. To make a reverting call, the subscriber consults a list of the subscribers on his own line and dials the number given for the desired station. He then hangs up his receiver. The alternate ringing begins and continues until the called subscriber removes his receiver from the hook and presses the hook-stop. The originating subscriber, noticing the cessation of his own signal, takes his own receiver, touches the hook-stop and proceeds to converse. Release is accomplished when both subscribers hang up their receivers. If the called station fails to respond, the originating subscriber stops the ringing by removing his receiver pressing the hook-stop, and hanging up the receiver again.

The line requirements for rural lines are as follows: maximum safe loop resistance 1000 ohms, minimum safe insulation resistance, wire to wire or either wire to earth 25,000 ohms. Any commercial telephone cable has low enough capacitance not to affect dialing.

Automatic switching offers to the rural subscriber a telephone service which is vastly superior to manual service and only slightly inferior to city automatic service. He has the same instantaneous, positive, direct calling at night as at noon, and on holidays as on work days. It is inferior to city automatic service only in the loading of the party line with so many telephones. In fact the moving force which hastened the application of automatic switching to rural lines was the pressure exerted by the farmers themselves to be given calling devices.

THE COMMUNITY EXCHANGE

The community exchange, as the term is now used, is a small unattended plant, whose toll switching and miscellaneous calls are handled from a distance and whose apparatus is often designed with the requirements of rural lines primarily in view. The community which it serves may be the farmers of a region, a small village or town, or the small suburb of a town. The traffic is chiefly local though by no means confined to the local telephones.

Miscellaneous services, such as information, complaint, dead numbers, etc., are usually cared for by the nearest public exchange where such service is maintained. Most of these community automatic exchanges are auxiliary to the ordinary type of public exchange. When the C.A.X. subscriber dials the information number, the call is trunked to the information clerk in that exchange, where records are kept for all the territory served.

Toll switching is handled in the same way as the above mentioned miscellaneous services. In fact it may pay to combine on one call number all these things, because one person can care for them all. The toll line operator is provided with a calling device and trunk connections to the community

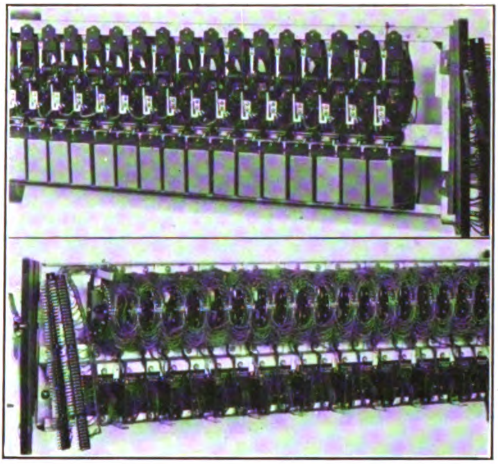
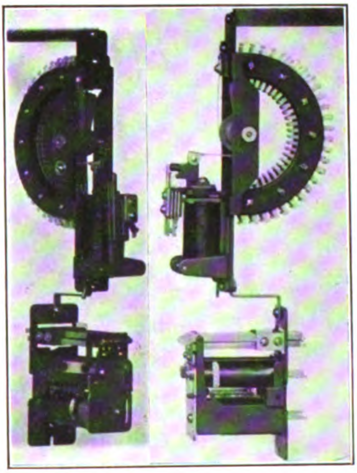


FIG. 7—ROTARY LINESWITCHES ON SHELF (FRONT AND REAR)



[SMITH]

FIG. 8—ROTARY LINESWITCH (LEFT AND RIGHT VIEWS)

automatic exchange, so that she can complete and control any connection.

The subscribers requirements are the same as for any single office exchange with rural lines. From the standpoint of the operating company, the apparatus must require little attention and the investment must not be too large.

The characteristics of the equipment are influenced by the conditions of the particular installation. Too great rigidity of standardization would result in inefficiency. This will become apparent as we study the matter farther.

The rotary line switch Fig. 7, is the regular equipment for community automatic exchanges. It possesses simplicity of structure, individual control, minimum of motion, and greater trunk group than the plunger type.

The rotary line switch Fig. 8, is a single-motion switch, with a 25-trunk bank set vertically. The motor magnet armature has a pawl which normally locks the wipers on any trunk. The wipers rest where last used. When the magnet energizes, it withdraws the pawl so that it catches the next tooth on the ratchet wheel. When the magnet de-energizes, the armature spring drives the pawl and rotates the wipers to the next trunk contacts, and locks them there. The magnet is self vibrating, like a door bell.

Associated with the switch proper is a line relay and a cut off relay. They are mechanically interlocked so that if the line relay is de-energized, the cut off relay can pull up only part way—just enough to break contacts and clear the line of attachments. If the line relay is energized, the cut off relay can pull up all the way, connecting the subscriber's line to the wipers.

When a call comes through a connector to the subscriber, the connector energizes the cut off relay alone. This clears the line of line relay and ground, but does not connect the line to the wipers. Thus there is a clear pair of wires from the connector to the subscriber's telephone.

When the subscriber originates a call, by lifting the receiver from the hook, the line relay pulls up and causes the trunk to be tested. If the trunk is busy, the magnet rotates the wipers at a speed of 60 to 80 trunks per second until an idle trunk is found. The magnet then stops, the cut off relay pulls up, clears the line, and extends the line to the first selector. During conversation, the cut off relay alone is energized. On release the cut off relay merely falls back—the wipers remain where they are. If the trunk upon which the wipers were resting at first is idle, the cut off relay pulls up completely and without delay. The time required to seize the trunk is only that required for two relays to energize. The maximum time required, if the wipers must pass over 24 trunks, is about half a second.

Most calls take an idle trunk without moving the line switch wipers at all. Tests made on a busy private automatic exchange showed that about 16 per cent to 20 per cent of the calls moved the wipers one or more steps—the rest of the calls required no motion.

Because it possesses no common mechanism, the rotary line switch lends itself admirably to rural exchanges. There is so little to get out of order, and the factor of safety is so large, that it can be relied upon to require very little attention. And if any one part *should* fail, it affects only one subscriber line instead of a group of lines.

The most important variable factors are herewith presented and will be discussed in detail.

1.	Transmission	Local battery or common battery
2.	Line relay	Double wound or ground relay
3.	Line equipment	Lineswitch or selector
4.	Signalling	Selective or code
5.	Signal control	Push-button or periodic
6.	Reverting calls	Push-button, periodic or hand generator
7.	Battery charging means	Motor generator or gasoline engine
8.	Battery charging method	Float or hand start with automatic stop

The tendency is to use common battery transmission as far as possible. The replacement of dry cells is a great and increasing expense. It is to be incurred only if the salvage of present equipment causes it to seem more profitable to retain the local battery, or if the lines are so long that it is necessary for good transmission. As far as automatic operation is concerned, it makes no difference which is used. Most lines are long enough to require a special weak current common battery transmitter. In all cases the polarized receiver is necessary, because the subscriber must be able to listen through a condenser to see if the line is in use.

The line relay (LR-Fig. 6) which handles the impulses should be connected to the positive or grounded battery terminal. Here it has a greater factor of safety than if it has two windings, one being to each battery terminal. If the line conditions are as good as in town, the usual double-wound line relay is fully adequate.

The usual practise is to carry all lines in a community automatic exchange to line switches. All selectors and connectors are usually equipped with the ground line relay circuit, so as to render repeaters unnecessary.

In regions where rural subscribers have been using local battery magneto telephones for years and are accustomed to code signals, the code signal can still be used with automatic. The non-secret nature of the call is by some regarded as a positive advantage. It is difficult for the city-dweller to realize how the farmer uses his telephone. An instance will illustrate one point. One evening Jones repeatedly heard his bell give the signal for the Browns, who lived a quarter of a mile down the road. Knowing that the whole Brown family had gone to town for the evening, he stepped to the telephone, and gave the calling subscriber the information. More congested rural regions seem to require greater secrecy, and the selective signal is favored and sometimes even requested.

The signal may be controlled by the subscriber or by the central office apparatus. The former is called "push-button control" or "push-button ringing." If it be code signalling, the subscriber presses a button on his telephone so as to form the signals. They may be thus made more accurately and easily than by the hand generator, with its revolving armature which must be started and stopped several times in each signal.

To secure push-button ringing, the button is arranged to ground the negative line and open the positive line. The negative line relay remains energized and prevents the connection from releasing. The positive line relay controls the ringing apparatus.

Code ringing was described under the heading "Rural Telephone Lines."

Reverting calls are handled in accordance with the method of signalling used. If local battery magneto telephones are employed, the subscribers ring each other on the same line just as they did with the manual switchboard. If selective signalling is employed, the subscriber dials a special number and receives alternate signals as was described above, (Rural Telephone Lines.) If code signalling is used it may be either periodic or push-button controlled. The latter requires reverting selectors, available to the party lines.

When a rural subscriber desires to call a person on his own line, he dials a special number. He then presses his push-button to form the code signal. This action controls a relay in the reverting selector, which sends ringing current back onto the originating line.

If the code ringing is periodic, reverting calls are handled by reverting connectors which are equipped very much like the regular connectors. The subscriber consults a list of subscribers on his own line (posted on the telephone.) He then dials the special number given for the desired station and hangs up his receiver. The desired code signal is sent back on the line, repeated periodically. When the called stations answer, the ringing is cut off—the originating subscriber then comes in on the line. Both subscribers hanging up release the reverting apparatus.

The charging of the battery is done preferably by a motor generator run by commercial power. The battery bus bars are equipped with a voltage relay, which starts the motor generator whenever the pressure falls to 46 volts and stops it when it reaches 52 volts. A self-closing reverse current circuit breaker stands between the generator and the battery. When the generator voltage is high enough to be safe, the circuit breaker closes and the charging begins. When the motor has been cut off by the high voltage, the generator voltage dies away until a slight reverse current operates the circuit breaker and cuts off the circuit.

If no commercial power is available, a gasolene unit is installed. This is started by hand as often as necessary. The regular maintainer need not do it, some one who lives near the exchange and is familiar with gasolene engines is employed to set it to going. The stopping is automatic. An ampere-hour meter is included in the battery circuit. It is compensated so as to run slowly when charging, but full speed when discharging. When the meter indicates the necessary ampere-hours have been put into the battery, it opens the ignition circuit of the engine, so that the latter stops. The circuit breaker disconnects the generator from the battery. During the time of charge, the circuit breaker inserts counter e.m.f. cells in the discharge lead to the power board—they prevent undue rise of voltage on the bus bars which would prematurely stop the charging.

The equipment is made up in three general units, the switchboard, the storage battery and the charging machine. The switchboard is made in two or three parts, which are installed side by side so as to form one unit. These parts are the local switchboard, the powerboard and the main distributing frame, and the trunking board. The latter is omitted if the exchange is isolated (no trunks to other exchanges.) All but the trunking board have been fairly well standardized. Because of the many variable conditions to be met in different places, the trunk board, containing selectors and repeaters, is made up in accordance with the needs.

A community automatic exchange needs no special building to house it. It has been installed in a store, in the bedroom of a residence—any convenient place which is available. There are signals to indicate when a fuse blows etc. The conditions of community life and the location of the apparatus are such that someone is always not far away.

This type of exchange has not been in service long enough to secure data of general worth as to the amount of maintenance labor required. In one case a group of three of these exchanges located on a straight line 26½ miles long, together with the telephones belonging to them are maintained by one man. The man is of the same general type as those who maintain ordinary automatic equipment.

The line requirements are the same as those given under "Rural Telephone Lines."

TOLL SWITCHING

Toll service between line and subscriber may be handled in any one of a number of ways. The methods described here are considered the best, as the result of much experience. Person to person calls alone are considered.

The recording toll clerk receives calls from the subscriber over trunks which come from selector banks and terminate on desks. The tickets are made out and passed to the toll line operator in the usual way.

The toll line board is provided with trunks which pass to toll selectors. Over these trunks the toll operator dials the full directory number by using a calling device which is keyed into the circuit. The selectors lead to toll connectors, the latter located in the hundred-line boards, adjacent to the local connectors.

These toll connectors may be used for local service as well.

If all the local connectors are busy, the local traffic will take one or more of the toll connectors. In this case the connector acts like a local connector, having the same current supply relays and condensers. When seized by a toll selector, the local apparatus in the toll connector is cut out, leaving a clear circuit from the last selector through the connector to the calling line. The last selector supplies current through a repeating coil.

The ringing is intermittent, but must be started by the toll operator. When the subscriber answers, the ringing stops automatically. If the subscriber hangs up his receiver, the usual supervision is given, and the toll operator may start the ringing again, if desired.

Intermittent ringing is used for toll calls because it has been found to be the more effective than manual ringing. Where local ringing is periodic and toll calls are rung by hand, much delay results. The subscriber is inclined to think that the manual ring is merely some local call which is very shortly released. Consequently he pays no attention to it. But the periodic signal gets his attention and greatly shortens the time of response to toll as well as to local calls.

The toll connector tests the called line as does any connector. If the line is busy, it sends a busy tone to the operator and also extinguishes the supervisory lamp at the toll board. When the line becomes free, the connector seizes the called line, stops the busy tone, and lights the supervisory lamp at the toll board. When the toll operator sees that the line is free, she starts the ringing by pulling a key.

The release of a toll-to-local connection is controlled by the toll operator. Merely pulling the plug out of the trunk jack causes the switches to be restored to normal.

TOLL SWITCHING BETWEEN EXCHANGES

It is desired to discuss under this heading the general considerations involved and to give some concrete illustrations of how exchanges are linked together.

General Considerations. The linkage of exchanges of any kind into a network requires, beside the toll lines, adequate means for switching these links to each other and to the lines of the subscribers who are to talk to each other. In arranging this switching, thought must be given to the cost of effecting such connections, and the effect of the means on the volume of traffic handled.

The usual manner of handling such calls is to have one or two operators in the originating exchange to connect the originating telephone and the toll line together, another operator at each switching office for toll lines, and one or two operators at the called exchange to connect the toll line to the called telephone. If each exchange has several offices and private branch exchanges, still more operators may be required.

It has been found that the manual switching of toll lines, among themselves and to the subscriber lines, entails considerable loss of time. This is chiefly due to the time required to gain the attention of operators who have other lines to serve beside the one in question. It lengthens the time required to set up a connection, it interferes with supervision, and delays the release of the circuits after both subscribers have hung up their receivers. This is so great a drag on the service that it has led to the establishment of many direct toll lines between important points, so as to do away with intermediate switching. This lowers the time-efficiency of the long direct line, because it can not be used for any intermediate traffic.

For at least twelve years toll lines have been switched by automatic means and experimenters have been at work producing apparatus which is adapted to this service. The first discovery made was that automatic switching increased the capacity of the toll line at least fifty to one hundred per cent. This remarkable increase is due to the speed of connection, the accuracy and promptness of supervision, and the quick clearing of the line after both subscribers have hung up their receivers.

No matter how the switches are controlled, the line must permit manual operation at any time, must operate automatically in both directions if both ends are at automatic exchanges, when seized must give positive indication to all stations concerned and must give supervision of both originating and called subscriber to the one operator who controls the connection.

Uniform operation is highly desirable. This point has received attention in developing automatic switching over toll lines. It is so arranged that if the operator plugs into the jack of an automatic toll line and rings, the call will go through manually as formerly. But if, after plugging into the jack, the operator throws the calling device key, she can put the call through automatically. After dialing the number, the operator rings with the regular ringing key. This operation holds no matter whether she is switching toll lines only, or if she automatically completes the connection to the called subscriber.

A few illustrations will show how automatic switching is applied to various toll traffic services. In order to avoid confusion, the examples will be very simple.

Consider the case of two adjacent exchanges which have free service from one to the other Fig. 9. Let each exchange be represented by four hundred-line-boards, having selectors and local connectors.

The lines (1 and 2) which carry the inter-exchange traffic are equipped at each end with a selector, and are in addition multipled to the banks of local selectors. A repeater is inserted between the selector banks and the lines for the purpose of holding the local switches from releasing, feeding common battery for talking, etc.

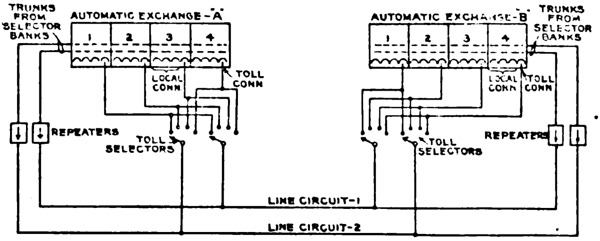


FIG. 9—AUTOMATIC EXCHANGES CONNECTED BY FREE AUTOMATIC TRUNKS

The banks of the toll selectors are run to the jacks of toll connectors, one in each hundred-line-board. These toll connectors have their banks multipled to the banks of the local connectors, so that all subscriber lines can be reached.

When a subscriber in exchange A desires to call one in B, he dials a figure which causes his first selector to seize one of the lines, making it busy on the banks of all other first selectors in both exchanges A and B. He then dials the directory number of the desired telephone, which first operated the toll selector at B and then the toll connector in the hundred-line-board chosen.

If pay service is the rule, the lines can be arranged so that the toll operator at the originating exchange can complete the connection without the aid of the toll operator at the distant exchange, Fig. 10. The toll lines will terminate at each end in toll selectors and jacks and lamps on the toll board. The trunks from local selector banks will also run to the toll board.

When a subscriber in B desires to call one in A, he dials a single figure number which causes his first selector to take an idle trunk to the toll board. The toll operator answers the call in the usual way. She has a calling device which may be associated with any pair of cords. When she plugs into the jack of the toll line, she makes it busy at both ends, showing the busy lamp at exchange A, so that the toll operator there will not try to use the line. The operator at B then dials the call through to the subscriber in A.

The operator at B controls the connection, giving it the usual supervision. When the subscribers are through, she pulls out the switchboard plug, which causes all switches to release.

The identity of the originating station may be verified by having the subscriber hang up his receiver. When the line connection is ready, the operator calls the originating subscriber automatically and permits conversation.

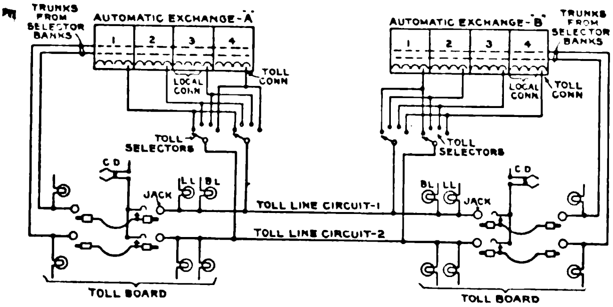


FIG. 10—AUTOMATIC EXCHANGES CONNECTED BY AUTOMATIC TOLL LINES

The apparatus is arranged so that the toll lines can be operated manually without change. If the operator after plugging into the toll line jack rings in the ordinary way, she will cause the customary lamp or drop to be displayed at the other toll board.

If between two such exchanges there is a toll central office, the lines can be interconnected by automatic switches with great saving in time. Consider, Fig. 11, four toll lines meeting at a toll office, which is manually and automatically operated. The former may be necessary for handling traffic to and from local subscribers.

Each toll line will terminate in three places, the toll board multiple, the automatic switch bank multiple, and the jack of the automatic switch belonging to that line.

If a distant exchange seizes a toll line, it is automatically made busy on the banks of the toll selectors and also lights the busy lamps belonging to it on the toll board. The distant exchange then dials the number of the toll line desired. When that line is seized, it is made busy on selector banks and toll board (as was the originating line.)

If the incoming call is for a subscriber in the exchange attached to the toll office, two ways are open for handling it. The distant exchange may ring on the toll line, cause the line signal to show on the toll board at the toll office and use the operator there to complete the connection manually or automatically. The second way is to run trunks from the banks of the toll selectors to the automatic switches of the local exchange and to permit the distant toll operator to dial through to the subscriber and supervise the call.

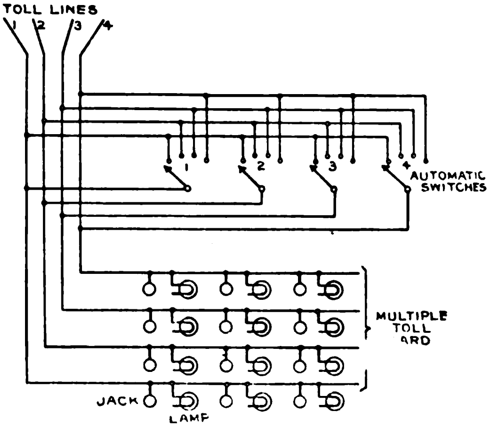


FIG. 11—AUTOMATIC TOLL SWITCHING OFFICE

The application of automatic switching to toll lines in a small net work will illustrate some of the possibilities. For the sake of simplicity, each exchange is limited to 1000 lines.

Let us consider five automatic exchanges Fig. 12. Four of them, A, B, C and D, are located at the corners of an approximate square. Exchange M is near the center of the quadrilateral. Assume further that free service is given between all adjacent exchanges, but that a charge is made for traffic between opposite corners (A and D, B and C). The exchanges are numbered from 1 to 5 as indicated.

The exchanges are connected by lines. To keep the illustration simple, assume that there is only one line between adjacent exchanges, eight lines in all. Any link can easily be increased by adding lines and switches without changing the principles described.

Each exchange has two kinds of first selectors, local and incoming. The local first selectors (illustrated by only one, L) handle all the traffic originated by subscribers in that exchange. One bank level carries the traffic into the local switches to local subscribers. Since this is a small system, to keep the numbering uniform, each exchange has a different local level. In A it is the first level, in B it is the second level, etc. The other levels lead to adjacent exchanges, each according to the number of the exchange. From the second level, a trunk goes through a repeater (R) to the line leading to B, where it terminates on an incoming selector (I–A from A, I–D from D, etc.)

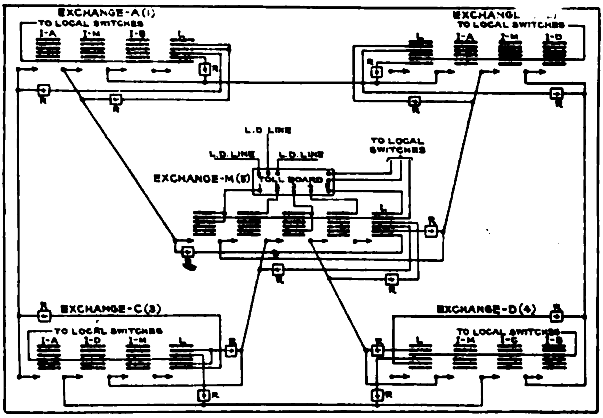


FIG. 12—TYPICAL NETWORK OF SMALL AUTOMATIC EXCHANGES

From the third level a trunk goes through a repeater (R) to the line leading to C, where it terminates in an incoming selector (I-A from A, I-M from M, etc.)

The repeater inserted in the outgoing trunk holds the local switches in the originating exchanges.

The incoming selectors (I–A, I–B, etc.) have the right level multipled to the banks of the local selectors (L) so that they have access through the local switches to the local subscribers.

These free lines are in reality two-way trunks. Each end of a line is attached to an incoming selector for incoming traffic and is multipled to the banks of all the local selectors (L) for outgoing traffic.

Suppose that a subscriber in exchange A calls a subscriber in exchange C, whose local number is 3225. The subscriber in A will first dial the figure "3" which causes his first selector (L) to lift its wipers to the third level and seize the line to C, making it busy at both ends so that no one else can intrude. Then he dials the figure "3" of the local number, which causes the wipers of the incoming selector (I-A) to rise to the third level and to seize an idle trunk to second selectors. The remaining three digits choose the hundreds, tens and units and complete the call.

To handle pay traffic between A and D and between B and C, as well as between the network and the long distance lines to other parts of the country, a toll board is installed at M. All incoming selectors in M have the fifth level multipled into the banks of the local selectors (L) because all the other exchanges are to call M free of charge. But the tenth or "0" level is run separately to the toll board. Any call for long distance by a "C" subscriber will go directly to the toll board, because the directory lists the long distance operator so as to secure that result. "Long Distance" may be listed as "50" or as "00", because the banks of the local selectors (L) at each exchange can be multipled that way.

Trunks from incoming selectors at M and the toll board are kept separate, so that the toll operator knows the origin of each call which comes to her.

If a subscriber at A desires to call some one at D, he is instructed by the directory to call "50" which leads his call to the toll board. The operator makes the charges and completes the call. The operator has lines leading into the local switches through which any exchange is available. If desired, special toll selectors may be set aside for her use. If the identity of the calling station is in question, the operator directs the originating subscriber to hang up. Then she calls the number which he gave, this establishes identity.

If the subscriber at A tries to avoid payment by calling through B or C, he will fail. The incoming selector (I–A) at both these places does not have any connection on its bank for the D exchange. It is impossible to get out of that place. If he tries to dial from A through M, to D, he will run against the same difficulty.

It is possible to multiple the banks of local selectors so that if a subscriber tries to evade payment, his call will be diverted to the toll board. This is done by connecting the level which will be called to the level carrying the trunk to (see exchange C.)

Suppose that a subscriber in D has business with a subscriber in B, whom he calls frequently free of charge by dialing "22" plus the rest of the number. If that D subscriber moves to C and attempts to call "22" as before, he will find himself answered by the toll operator at M, who will make the charge and complete the call. Level "2" of local selectors in C is multipled to level "5" and the trunk to M. The incoming selector (I–C) in M has its second level multipled to the tenth and thus to the toll board.

LONG DISTANCE TOLL LINES

It seems to the writer that there is no insurmountable obstacle to prevent the extension of the automatic switching of toll lines to include long distance lines of any length. The only limit is that of desirability. Any distance over which telegraph can be worked can be covered by automatic dialing on toll lines. The problem is more difficult than straight telegraphy, for the transmission of the voice must be safeguarded. But as the advantages become more generally known, automatic switching will be extended as far as there is any advantage to be gained. The farther two points are apart, the more line there is involved in each conversation and the greater the need of economizing time.

THE COMPREHENSIVE SYSTEM

The automatic switching of telephone lines of all kinds is available for building up a comprehensive telephone system of large usefulness. It serves equally well the farmer, the small town dweller and the citizen of the metropolis and links them all together. Everywhere that telephone lines are to be joined and disconnected, and where human intelligence is not absolutely indispensible, the automatic switch materially increases the efficiency. Every year people are revising their views on what constitutes a real need for human intelligence, and this revision is not confined to any one industry.

Gradually the use of automatic switching is extending its usefulness and raising the effectiveness and the efficiency of the whole comprehensive system.

SUMMARY

Automatic switches made with reasonable care, to well known and definite limits, give superior telephone service with plenty of margin to spare. Automatic switching is not so easy that any kind of apparatus thrown together in any sort of way will give good service; neither is it so difficult that prohibitively expensive machinery barely secures commercial results.

The ways of connecting automatic switches together so as to form a smoothly operating system are many and varied, and permit adaptation to any class of telephone service. It meets the need for telephony, not as manual switching meets it, but in its own way, which in many particulars is better. This art rests upon a reasonable and scientific foundation.

To be presented at the 356th Meeting of the American Institute of Electrical Engineers, New York, December 12, 1919.

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THE SEARCHLIGHT IN THE U. S. NAVY

BY RALPH KELLY

Abstract of Paper

The types and uses of searchlights and signaling lights on naval ships are briefly described.

A changed form of 12-inch incandescent light is suggested which will insure the lamp bulb filament always being at the focal point of the mirror and of the correct type for the application.

The present type of low-power searchlight has many faults. These faults may be corrected by supporting the carbons rigidly near the arc, the positive carbon being held at the focal point by a simple automatic control. The best size and material of carbons should be used regardless of the burning ratio.

The introduction of the high-power searchlight revolutionized the application of the searchlight to naval ships. Although great improvements have been made since that time there is room for a material reduction in the number and complexity of the parts.

It is believed there is also a possibility of a considerable improvement in the electrodes.

The use of the dome glass door enables a searchlight to operate in close proximity to large calibre rifles and makes it possible to successfully build even larger sizes of searchlights than those at present in use.

The star shell has great possibilities, but it is doubtful if it will ever supersede the high-power searchlight.

THERE are three distinct types of searchlights commonly used in the United States Navy:

The incandescent searchlight,
The low-power searchlight,
The high-power searchlight.

These types are used for navigational work, for both daylight and night signaling and for illumination of enemy ships in night engagements. Each type has its field of usefulness in navy work.

The development of the searchlight for naval use was practically dormant for the few years prior to 1915.* In 1915 it was revived by the adoption of the high-intensity light on Capital Ships after a long series of tests under laboratory and sea-going

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* "Searchlights" by C. S. McDowell. TRANSACTIONS A. I. E. E. 1915.

Manuscript of this paper was received May 10, 1919.

conditions. Since that time the development has been so rapid that searchlights purchased in one year became almost entirely obsolete the next year.

The object of this paper is to describe the various types of searchlight equipment at present in use in the navy, their field of application and the paths of future development demonstrated by experience gained during the war. It is hoped that there will be a free discussion along constructive lines of the suggestions for future development of searchlight equipment for naval use.

THE INCANDESCENT SEARCHLIGHT

At present there are four separate forms of the incandescent searchlight used in naval service:

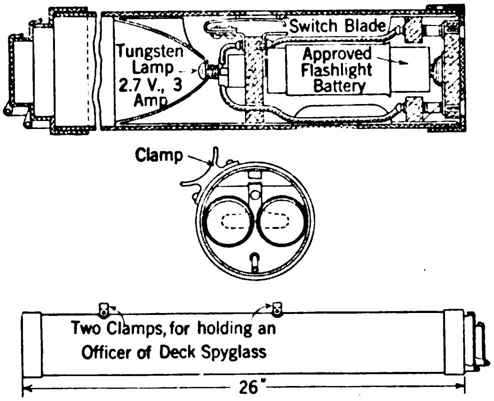

Tungsten Lamp 2.7 V., 3 Amp
Switch Blade
Approved Flashlight Battery
Clamp
Two Clamps, for holding an Officer of Deck Spyglass
26"

FIG. 1—THE PORTABLE TUBE BLINKER

The portable tube blinker,
The yard-arm blinker,
The Aldis light,
The 12-in. incandescent light.

The two blinkers cannot properly be classed as searchlights as they are used only for signaling purposes. As all sizes of searchlights are largely used for signaling, a description of these lights is included to make the article complete.

(*a*) *The Portable Tube Blinker*, Fig. 1, is extensively used for concealed local signaling at night between ships in column, between neighboring columns of ships or between landing parties on hostile coasts and their supporting ships. It is accordingly designed to throw a feeble beam of light of a very contracted area in order to avoid its being observed at long ranges or by anyone at whom it is not directly aimed.

It consists of a long brass tube with a small flash lamp bulb placed at one end at the focal point of a comparatively large parabolic reflector with a short focal length. The reflector is designed to project practically all the light from the lamp bulb in the form of a small diameter beam to the neighboring ship or station. The inside of the tube is painted black and has a long extension between the lamp bulb and the opening in the tube end. This tends to eliminate all stray light, keeping the beam to a small diameter. This form of signaling light performs its duties well and is universally used in naval service.

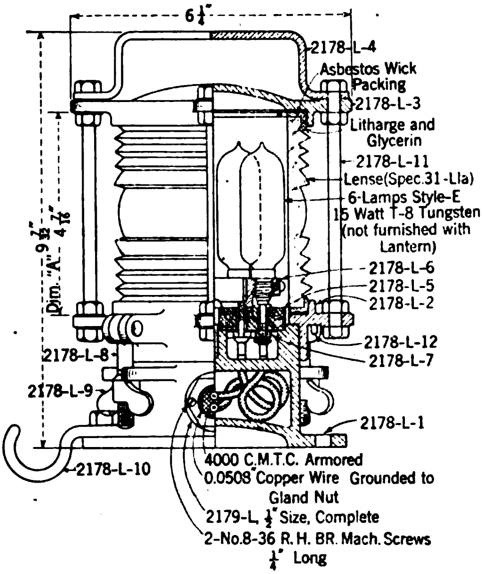

6¼"
2178-L-4
Asbestos Wick Packing
2178-L-3
Litharge and Glycerin
2178-L-11
Lense(Spec.31-Lla)
6-Lamps Style-E 15 Watt T-8 Tungsten (not furnished with Lantern)
2178-L-6
2178-L-5
2178-L-2
2178-L-12
2178-L-7
2178-L-1
Dim. "A" 9 7/32"
4 7/16"
2178-L-8
2178-L-9
2178-L-10
4000 C.M.T.C. Armored 0.0508" Copper Wire Grounded to Gland Nut
2179-L, ½" Size, Complete
2-No.8-36 R.H. BR. Mach. Screws ¼" Long

FIG. 2—YARD-ARM BLINKER LIGHT

The only fault that has developed in its use is a minor one which may be easily corrected. When used on a small boat forming an unsteady platform, such as a destroyer or submarine chaser, it is very difficult to keep the blinker directed at the desired receiving station due to the blinker rolling on the rail. A rectangular cross section of blinker or a ball and socket rest on the rail for the present style of blinker would improve the operation.

(*b*) *The Yard-Arm Blinker,* Fig. 2, as its name implies, is a blinker lantern mounted on the yard-arm of a ship and which gives out light that is visible all around the horizon. It is widely used for night signaling in times of peace and in protected waters in times of war. The lantern is designed to contain a high-speed incandescent light with a filament which is placed at the focal point of a Fresnel lens. Signals are sent by blinking the light with a telegraphic key which alternately makes and breaks the circuit. The lamp bulb used in this lantern has been specially developed for Navy signaling work with a concentrated filament that heats and cools very rapidly.

This type of blinker has given general satisfaction and is a valuable addition to the signaling equipment of a ship in view of the large amount of signaling that takes place between naval vessels. In actual practise a circular nest of six commercial tubular lamb bulbs, connected in parallel across the line, are used instead of the correctly designed high speed signal lamp bulb with its filament at the focal point of the lens.

No part of the filaments of any of these lamps coincide with the focal point of the Fresnel lens with the result that the lens disperses all except the direct rays of light to the observer, and could be replaced with a less expensive plane glass cylinder. The nest of lamps with a comparatively long life is used by navy personnel in preference to the short lived high-speed signal lamp, as the blinker lantern is located at the end of a yard arm. Any lamp combination that requires infrequent replacements is for this inaccessible light more popular with the bluejacket than a better short-lived lamp.

The nest of lamps, as far as can be determined, gives entire satisfaction in signaling work, making it possible to replace the comparatively expensive Fresnel lens with an inexpensive plane glass cylinder.

(*c*) *The Aldis Lamp*, Fig. 3, is a projector of British design in which advantageous features are incorporated that make it superior to similar lamps previously used in naval service. While primarily designed for daylight signaling, it has been used successfully as a searchlight and for signaling in airplanes and dirigible ballons.

The projector itself is a light, well balanced, portable affair of aluminum which signals by alternately throwing a searchlight beam on and off an observer. This is accomplished by rocking the mirror back and forth by means of a trigger, the lamp bulb burning continuously. The lamp bulb is manu-

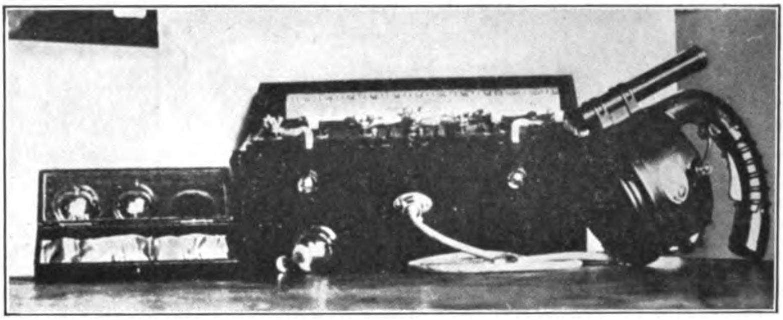


Fig. 3a—Complete Aldis Lamp Equipment

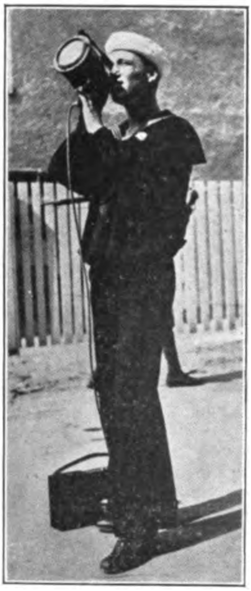


Fig. 3b—Aldis Lamp in Service

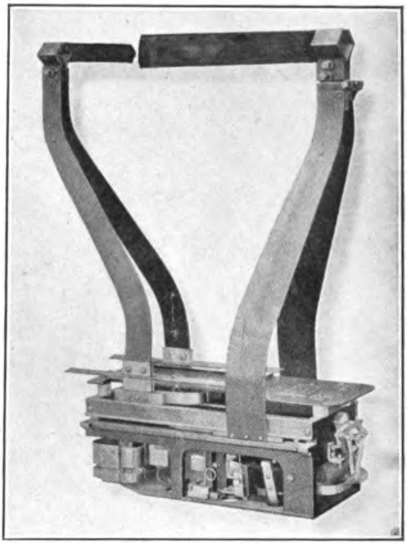
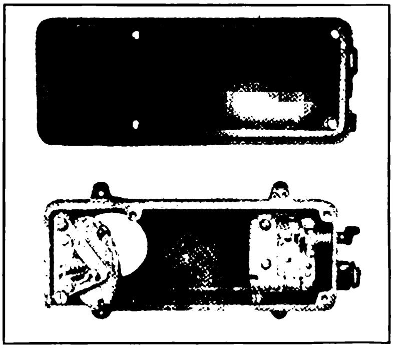


Fig. 5—Lamp Mechanism for a Low Power Searchlight



[KELLY]

Fig. 6—Thermostat Box and Cover

factured to such close limits that when it is screwed into a special socket in the lamp, its filament is in the focal point of the mirror.

This type of signaling lamp is universally used on ships, shore stations, dirigibles and airships. Its success is due to its high signaling speed, its compactness and portability, but most of all to the fact that, regardless of the personnel handling it, the lamp filament is always at the focal point of the mirror and a long range efficient beam is obtained at all times.

(*d*) *The 12-in. Incandescent Lamp* Fig. 4, is largely used in naval service on all classes of naval vessels for long range daylight signaling in fair weather, and for navigational use at night on small boats. This type of light has not been generally successful in its present form due to the fact that it requires special adjustments and care in service, for successful operation.

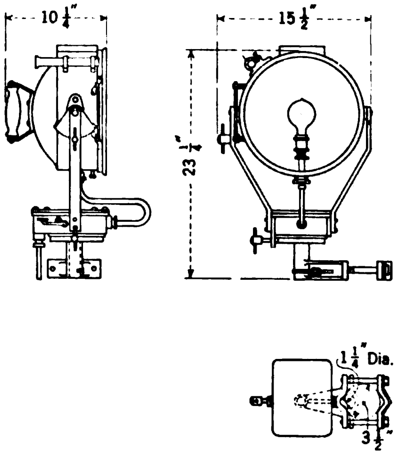


FIG. 4

It has a fixed parabolic mirror with a high-speed signaling lamp bulb which screws into a standard socket. The socket can be adjusted to place the filament of a commercial lamp bulb in the focal point of the mirror. This adjustment is made large to permit the use of several different sized lamp bulbs ranging from 150 to 400 watts. The whole is contained in a cylindrical drum which is commonly made of sheet iron. Signals are sent by blinking the filament of the lamp bulb by a telegraphic type of key.

This lamp has prooved successful for navigational work on small craft and particularly so for submarines. A small 9-in. arc lamp was specially developed for submarine use, but its lack of portability, attention required in operation, and necessity for frequent recarboning caused it to give way to the incandescent searchlight. An important factor that entered into this change is that a submarine is frequently submerged without there being sufficient time to dismount the searchlight and stow it below. An incandescent searchlight can be submerged without permanent damage, while an arc lamp is placed out of commission. The small amount of care required for the incandescent type of searchlight, and the comparatively long life of a lamp bulb in comparison with a trim of carbons, makes a correctly designed light of this type ideal for use on small craft with limited personnel.

The faults in the present type of light have been demonstrated by its use in daylight signaling. At the present time the correctly designed Aldis light, with a 4½-in. mirror and 40 watt lamp, is the equal in signaling power to the larger light with its 11-in. mirror and a 150-watt lamp. Considerable adjustment is permitted, both in the horizontal and vertical planes of the 12-in. incandescent light, to allow for variations in filament location in commercial lamps, and to permit the use of various size lamp bulbs. Every time a new lamp bulb is inserted in the projector, the operator should focus the projector for that particular filament. This is rarely, if ever done, and in service in not one lamp that the writer has inspected has the lamp filament been at the focal point of the mirror. In the majority of cases it has been approximately one inch out of focus in each plane. Of course in this condition the mirror is of no value and only the direct rays of light from the filament reach a distant observer.

The high-speed concentrated filament lamp bulb specially designed for this searchlight is almost identical in appearance to a concentrated filament stereoptican type of lamp bulb designed only for searchlight work. Long life being desirable in the latter type of lamp, its filament cools and heats very slowly and it cannot be used at all for signaling work. Due to the similarity in appearance, both types of light are issued indiscriminately for the 12-in. searchlight. The personnel, not realizing that there are two entirely different types of lamps of similar appearance, condemn them both and use a commercial Mazda lamp which happens to fit the same socket, but in which no part of the filament comes any where near the focal point of the mirror.

The design of a new type of light along correct fundamental lines, is contemplated to be arranged so that it cannot be used incorrectly by naval personnel. The same type and size of mirror will be used in a brass non-corrosive drum. The lamp socket will be permanently fixed in such a position that when a 150-watt, high-speed lamp bulb is placed in it, some part of the filament will be in the focal point of the mirror. The ordinary high-speed 150-watt lamp is manufactured with a dimension across the filament of approximately ¼ inch so that in the great majority of cases with such a lamp, some part of the filament will be in the focal point of the mirror, even with ordinary commercial limits of manufacture.

To eliminate the use of lamps other than that specially designed for this class of work, the lamp bulb must be of such design that no other lamp can be used in the socket. One way of accomplishing this object is to make the signaling lamp with a bayonet base. Similar precaution will have to be taken in a 12-in. incandescent searchlight that will be used only for searchlight work to provide only for the use of a concentrated-filament, long-life, stereoptican light.

Attempts have been made to extend the use of the incandescent searchlight to larger sizes such as 18- or 24-in. using larger wattage lamps. To obtain the larger lamp capacity; the filament area must be increased with the result that the intrinsic brilliancy of the filament remains approximately the same and there is practically no increase in light. There is no attempt being made at the present time to increase the size of the incandescent searchlight beyond the 12-in. size.

LOW-POWER ARC LIGHTS

The number of sizes of low-power arc lamps in navy service at the present time is legion, a 9-in., 12-in., 18-in., 24-in, 30-in., 36-in. and even a few 60-in. are used. The large number of sizes is a natural growth during a long period of years, new sizes having been developed for special application.

The 9-in. size was developed specially for submarine work and is practically the 12-in. size of lamp with a few necessary modifications to fit it to the smaller drum. It has recently been superseded for submarine use by the 12-in. incandescent search-light.

The 12-in. size is the most commonly used of all searchlights in naval service. It is used principally for long range daylight signaling on all naval vessels and for navigational lights on small boats. It has a wide field of usefulness and practically every naval ship has at least one of these lights as part of its equipment.

The 18-in. searchlight prior to the present war was used only on merchant vessels. Although the present type is not well constructed, a large number of them were purchased when the United States entered the war as there was a great shortage of searchlight material at that time, and a large number of ships to be equipped.

The 24-in. low-power light has a limited application for navigational work on naval vessels, such as hospital ships, fuel ships and tenders of all types and a certain field for long range daylight signaling.

The 30 and the 36-in. low-power searchlights were placed on battleships and cruisers prior to the development of the high-power searchlight. They are rapidly being replaced by high-intensity lights or being converted into high-intensity lights and will shortly be obsolete in naval service.

It would be of great advantage in the future to use only one size of low-power searchlight, 12 in. or 18. in., developing a searchlight along fundamentally correct lines to give a far greater beam candle power under operating conditions than the present 12-in. light. It is believed that a new 12-in. light can be developed to give as great illumination on the target as the present 24-in. low-power searchlight.

All sizes of low power searchlights in service are essentially the same in design, the mechanism differing only in size. A typical mechanism is shown in Fig. 5. The positive and negative heads are each supported on a separate movable carriage. The carriages are separately geared to a motor or solenoid which feeds the two heads together at a predetermined fixed rate, which is supposed to correspond to the burning away of the carbons. The specifications for purchasing carbons call for carbons that burn at fixed rates which, combined with proper gearing in the lamp mechanism, will theoretically result in the positive crater being in the focal point of the reflector at all times. The arc length is kept fairly constant by a balanced type of feeding mechanism that feeds the negative carbon forwards or backwards when the arc voltage is higher or lower than normal. The present size carbons are of comparatively large diameter, slow burning and with a low current density.

This design of searchlight lamp has many inherent fundamental faults that may be easily corrected. Its principal fault in operation is that rarely if ever is the crater of the positive carbon at the focal point of the reflector. When it is considered that a cross wire deviation of 1/16 in. of the crater from the focal point of the projector will give a beam of approximately double the width and one quarter the intensity of a standard searchlight beam, it is realized how important it is to maintain the crater of the positive carbon at the focal point of the reflector. Carbons cannot be manufactured commercially to give the exact burning rates specified, but vary from that rate as much as 20 per cent in each direction in extreme cases. Specifying the burning rate of carbons is a distinct handicap to a carbon manufacturer tending to hinder the development of better carbons.

The carbons themselves are of comparatively large diameter producing an arc that has a tendency to wander over the face of the positive crater, resulting in an unsteady beam and a comparatively cool, low-intensity source of light for the searchlight beam. The intensity of a searchlight beam varies with the temperature of the positive crater which makes it desirable to have a carbon current density which will give the greatest temperature at the positive crater. Each grade of carbon has a definite boiling temperature and an increase in current density beyond that necessary to produce that temperature only causes the carbon at the crater to boil away faster with no increase in crater temperature. An ideal condition, therefore, is to use a carbon with the highest boiling point and a current density that will just produce a crater temperature that is equal to the boiling point of the carbon.

The carbon heads themselves are not rigidly supported and have a marked play in all directions. This play is so marked that the rolling of the ship will change the position of the carbons in the searchlight drum. The current is fed into the carbons at their butt ends and flows through the entire length of the carbon to the arc. This tends to heat the carbon throughout its entire length which often causes it to spindle. It also results in a variable arc length, for with a short length carbon the voltage across the arc is materially greater than with new long length carbons.

A correctly designed lamp mechanism for a searchlight should produce the longest arc length possible at which the arc will burn steadily, to reduce to the lowest possible value the shadow cast on the mirror by the negative carbon. The appreciable variation in arc length in the present type of low-power searchlight results in the negative shadow being materially greater during the majority of the burning of a trim of carbons than the best obtainable condition.

A 12-in. low-power searchlight could easily be designed to overcome the faults in the present low-power searchlights. Such a light would not only give a more intense beam than the present 12-in. searchlight under laboratory conditions, but in actual service its more exact mechanism would give a searchlight beam of very materially more power than the present inexact mechanism. The carbon heads in the proposed light would be rigidly fixed in position with absolutely no play nor adjustment, would have a simple automatic control of the positive crater to maintain that crater in the focal point of the reflector at all times, and would have the current fed into the carbons close to the arc. As in the present 12-in. searchlight, the arc length could be controlled by a solenoid feed. A ground glass finder should be provided to enable an operator to check the position of the positive crater.

The automatic control of the positive and the voltage control of the arc results in the carbons being fed independently of their burning rates. Accordingly, if improved carbons with different burning rates are developed they may be used in this lamp with practically no change in the lamp mechanism, a condition which is not possible in the present type of lamp. The carbons would be manufactured with diameters in the neighborhood of one half the present size, which would result in a higher temperature of crater, a closer approach to a point source of light and a smaller negative shadow on the mirror. These carbons should be made of the best combination of materials of the highest boiling temperature that will maintain a steady arc. These searchlights should be equipped with a Venetian blind signaling shutter to permit their being used for daylight signaling as well as for navigational work. Such a light would be suitable for daylight signaling and navigational work on battleships, cruisers, auxiliary ships, destroyers, seagoing tugs, transports; in fact for all naval vessels it would supersede the numerous sizes of low-power searchlights now in naval service.

The change would be of advantage both to the manufacturers and to the navy. The manufacturers will have to develop and keep in stock but one set of tools and patterns and can concentrate on the improvement and development of that one type of searchlight. The navy will benefit by having to keep a stock supply of only one size of low-power searchlight, which will require a stock supply of only one kind of spare parts and accessories like mirrors, lamps, rheostats, switches, shutters, etc.

High-Power Arc Lights

The invention of the high-intensity arc revolutionized the searchlight for naval use. The 30-in. and 36-in. low-power searchlights previously used had a maximum range of approximately 2000 yards on a dark, clear night. The present 24-in. high-power searchlight has a range of approximately 8000 yards and the 36-in. high-power searchlight has a range of approximately 15,000 yards under similar conditions. It is evident that the the low-power lights are useless in gunnery work with modern long range guns, while the ranges of the high-power lights compare very favorably with those guns.

The high-power searchlight swings to the other extreme from the low-power searchlight in that it is a very complicated exact mechanism with a large number of intricate parts which are designed to operate automatically. Its success depends on the socalled high-intensity phenomena obtained by the use of carbons with impregnated flame cores with high current densities, and arranged at an angle to each other. The material of the shell of the carbon is of hard amorphous carbon, the inside being a combination of special mineral salts with the necessary flame producing ingredients. At the beginning the core burns more rapidly than the shell, forming a deep crater which becomes filled with the flaming gases of the core. The combined effect of the high current density of the arc and the angle of the negative arc stream is such that these gases are imprisoned for a short period in the positive crater. These gases are heated to incandescence while imprisoned in the crater, and give a light that is far in excess in intrinsic brilliancy of that given off from the solid crater walls. This increase in intrinsic brilliancy of the source of light for the searchlight results in the superiority in range of the high power searchlight.

The carbon heads are rigidly fixed in the drum with mechanisms included in those heads for feeding the carbons. Contacts placed in the carbon heads, close to the arc, feed current in and out of the arc circuit. The arc length is kept approximately constant by a motor feed that is controlled either by the arc voltage or by arc current and feeds the negative carbon either backwards or forwards to maintain constant arc conditions.

The positive crater is kept at the focal point by automatic devices, either of the thermostatic type or of the third electrode type. Two of the companies manufacturing high power searchlights use a thermostatic control of the positive carbon while the other uses the third electrode control. In the thermostatic device, light from the positive crater is reflected by an optical arrangement of mirrors and lenses to thermostat strips placed in a box on the outside of the searchlight (Fig. 6). When the positive carbon burns back slightly from the focal point of the mirror, the reflected light strikes one of the thermostat strips, and distorts it by the heat. The thermostat strip in distorting closes an electric circuit which causes the positive carbon to feed forward. When it is fed forward to the focal point, the reflected light from the positive crater moves off the thermostat strip which cools instantly and opens up the feeding motor circuit.

This device has worked well in naval service and under the best conditions of operation will maintain the positive crater at the focal point within limits of 1/32 inch, plus or minus. The present thermostat mechanism is mounted on the outside of the drum in a box which is exposed to the weather. In every case in which the writer has inspected searchlights that have seen service, there has been either a considerable amount of water in the box or evidence of water having been recently in the box. Again, the searchlight lamp and the thermostat have a definite relation to each other and an adjustment of one requires a separate and independent adjustment of the other. A thermostat placed inside the searchlight drum and secured to the lamp standard would remedy both of these defects.

The third electrode scheme for controlling the positive crater is more simple and substantial than the thermostat and operates well under service conditions. This device (Fig. 7) consists of a carbon electrode placed above and at right angles to the positive carbon slightly behind the crater. When the positive crater burns back from the focal point, the flame of the arc strikes the third electrode completing an electric circuit of which the conducting flame of the arc forms a part. Current flowing in this circuit causes the positive carbon to feed forward. When the crater is fed to the focal point of the reflector, the flame clears the third electrode and the feeding motor circuit is broken. This type of positive carbon control has the advantage of being placed inside the searchlight drum out of the weather, and of being integral with the positive head requiring no separate adjustments.

The first type of third electrode developed was of carbon which required renewal every three trims of the searchlight carbons. There has since been developed a third electrode which is a copper disk, and which has a very much longer life than the carbons. In operation, a coating forms on this copper disk which protects the copper from burning and prolongs the life of the disk.

The intense heat of the high-intensity crater and the large amount of smoke and fumes emitted from the flame carbons make it imperative to have forced ventilation of the carbon heads and searchlight drum. An early type of high-power searchlight used the comparatively cool vapor of an alcohol flame to cool the carbon tips and the drum was exhausted by a fan connected to a separate motor. The cooling of the high-intensity searchlight was later improved by making hollow lamp standards, jacketing the carbon heads, and forcing air through these chambers and out through an outlet at the top of the searchlight drum, thus doing away with the alcohol flame method of cooling.

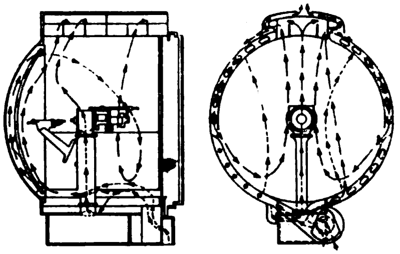


Fig. 8—Diagram of Ventilation of a High Power Searchlight

In the first high-power searchlights great difficulty was experienced due to the large heat absorption and unequal heating of the mirror and a great number were smashed due to these causes. This condition was finally remedied by efficient cooling of both the front and rear of the mirror by a current of air. The ventilating system of a modern high-power searchlight, showing the paths of cooling air around the mirror, is shown in Fig. 8. The heating of searchlight mirrors has been reduced during the past year by the development of a tough white glass of pure materials which has approximately one per cent heat absorption against the five per cent absorption of the grade of glass previously used for mirrors.

Three typical searchlights developed by the three present manufacturers of high-power searchlights are shown in Figs. 9, 10 and 11. An inspection of these illustrations shows the progress in development of these exact well designed mechanisms over the less refined, inexact, low-power searchlights.

The 36-in. high-power searchlight is the largest size used on shipboard for it gives a range comparable to the largest guns and is the largest, at the present time, that will withstand the heavy concussions of the ships gunfire. It is only very recently that the searchlight has been adapted to withstand the concussion of the gunfire of a nearby 14-in. gun. Prior to this time searchlights were equipped with glass front doors made of a number of plate glass strips. This type of front door cut off approximately 25 per cent of the searchlight beam, was not watertight and would smash at the first salvo of the main battery. The success of the ventilation system of the high-power searchlight depends on obtaining air through a duct in the bottom of the drum and forcing it through well defined paths and out through an exhaust outlet at the top of the drum. This scheme of ventilation is made ineffective when the front door is smashed with the result that the arc flickers and the searchlight parts become overheated due to an insufficient supply of cooling air.

The smashing of the front door strips leaves the mirror unprotected and it is an even chance that the mirror will smash at the next salvo from the main battery. It is common practise on shipboard to dismantle searchlights equipped with plate glass front doors before a target practise, and stow them away in a safe place.

This condition has been remedied by the use of a front door made of one solid piece of arch shaped glass similar in shape to the parabolic mirror. This type of door has given excellent service in the fleet and not one of the many dome glass doors that have been installed on navy vessels has been smashed during target practise. This type of door cuts down the searchlight beam no more than the plate glass strips and makes the searchlight entirely self-contained and waterproof.

The trend of future development of the high-power searchlight should be in the simplification and the reduction of the

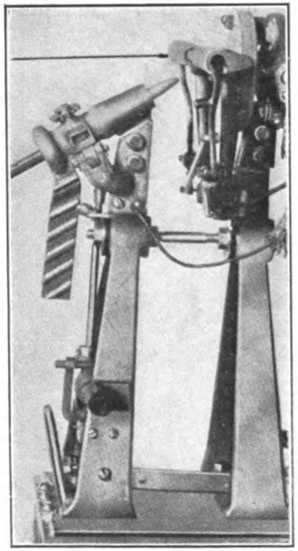


FIG. 7—SEARCHLIGHT LAMP WITH THIRD ELECTRODE CONTROL

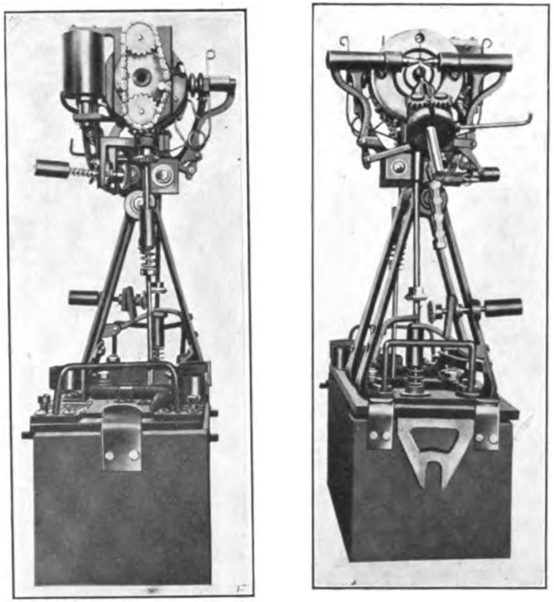


FIG. 9A—ARMA 75 AMPERE HIGH INTENSITY SEARCHLIGHT LAMP TYPE AA

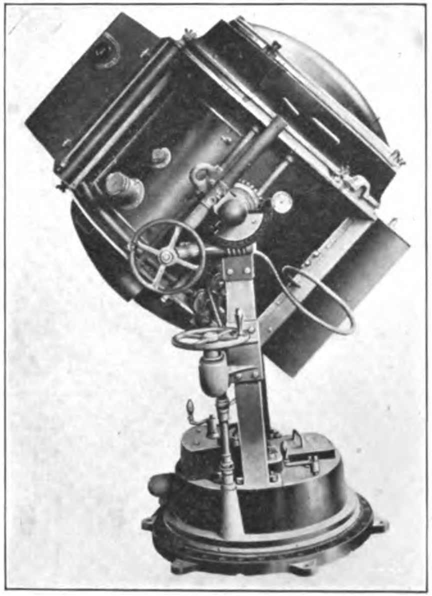


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FIG. 9B—ARMA 24-INCH HIGH INTENSITY SEARCHLIGHT TYPE B

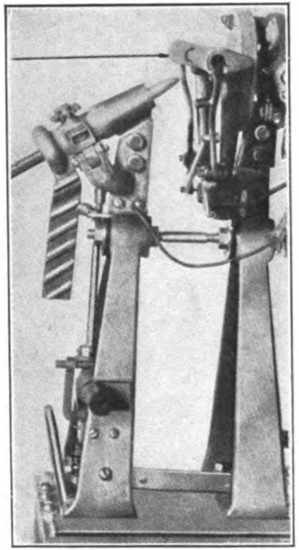

FIG. 7—SEARCHLIGHT LAMP WITH THIRD ELECTRODE CONTROL

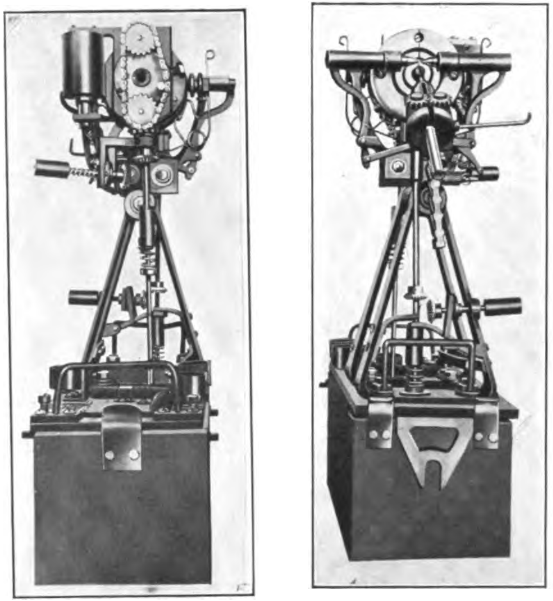

FIG. 9A—ARMA 75 AMPERE HIGH INTENSITY SEARCHLIGHT LAMP TYPE AA

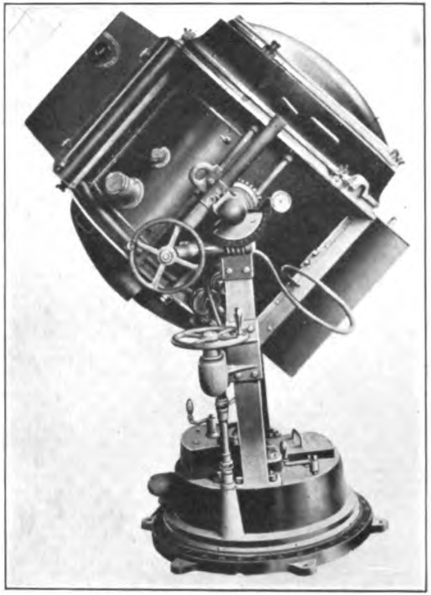

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FIG. 9B—ARMA 24-INCH HIGH INTENSITY SEARCHLIGHT TYPE B

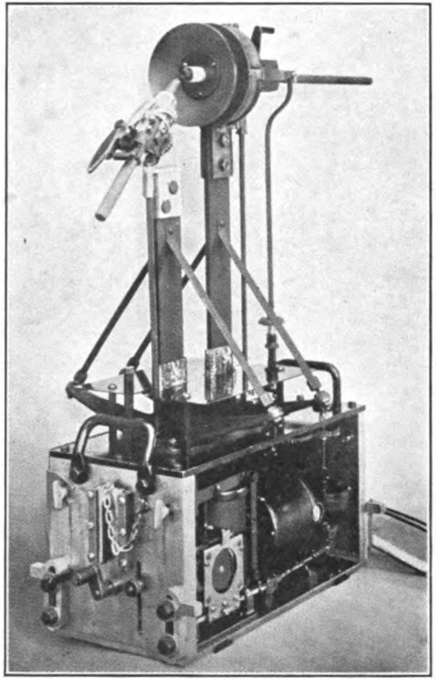

FIG. 11A—LAMP FOR 24-INCH HIGH POWER SEARCHLIGHT

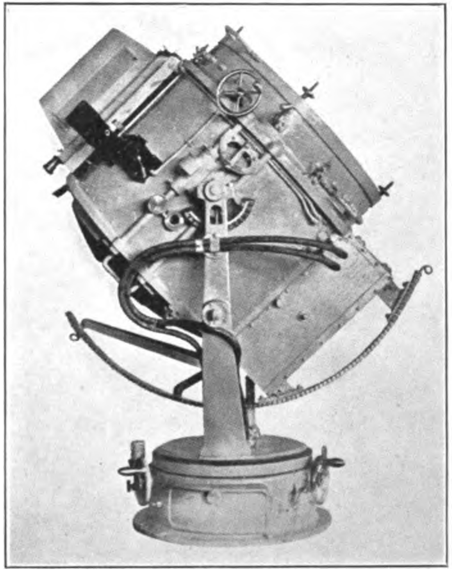

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FIG. 11B—24-INCH HIGH POWER SEARCHLIGHT

large number of intricate parts on the present searchlights. A searchlight must necessarily be placed in a position exposed to the weather, and will be operated by enlisted personnel. It is a struggle to maintain the present complicated high-power searchlight mechanisms in operating condition under the severe conditions of operation on smaller boats, like destroyers. After a few days at sea on a destroyer in rough weather, the present high power searchlights often become inoperative and require a number of hours overhaul to place them in operating condition. Such a searchlight soon loses its popularity with destroyer commanders and they justly complain that the high-power searchlight is more suitable for laboratory use than for destroyer use.

There is still room for a large improvement in the size and material of carbon electrodes for high-power searchlights. At the present time a carbon is used which has a hard carbon shell and a core made of a combination of flaming materials. This core gives off gases which are heated to incandescence in the arc and give the high intrinsic brilliancy light characteristic of the high-power searchlight. It also gives off a very brilliant flame which causes a correspondingly brilliant objectionable foreground illumination and gives off gases that tend to blacken the mirror and the front door.

It is a well established fact that the color and intensity of a searchlight beam is dependent only on the temperature of the source of light. The use of flame-colored salts in the electrode gives a high temperature but also burns with a large brilliant flame. It is believed that a proper selection of carbon materials, perhaps the use of a solid electrode of a very refractory carbon with a small negative carbon, will give the same amount of light that is obtained from the present high-power type of carbons. The flame from a combination like these would be practically transparent with no objectionable foreground illumination, the objectionable gases would be eliminated and the present type of very special carbon elctroedes could be done away with.

The star shell for gunnery work is also a factor in the development of high-power searchlights and bids fair to rival the larger high-power searchlights for gunnery work. A searchlight, unless skilfully and carefully manipulated, is more of a debit than a credit in action as it tends to give an enemy a definite point at which to aim. A star shell that satisfactorily illuminates the target, leaving its own ship in darkness, has many decided points of advantage over a large high-power searchlight.

However, even if the star shell gives the results claimed for it, it will be a long time if ever before naval authorities will feel safe in removing the 36-in. high-power searchlight from capital ships. The 24-in. high power searchlight has had such a marked success in long range daylight signaling that it is improbable it will ever be superseded for naval use.

The use of the dome glass door for 36-in. searchlights opens up a field for the use of larger size searchlights, such as the 44-in. and 60-in. sizes for capital ships, and it is believed if those larger sizes are ever required for naval service they can be successfully developed.

In closing the writer wishes to express appreciation to Major Howard C. Judson, U. S. M. C. for ideas contributed on carbon development.

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Next Meeting: New York, January 10, 1919
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See Page 1, Sec I.

NOMINATIONS FOR INSTITUTE OFFICERS

1919-1920

See page 2, Sec. 1

SEVENTH ANNUAL MIDWINTER CONVENTION

February 19-22, 1919

See page 1, Sec. 1

INSTITUTE MEMBERS IN SERVICE

HONOR ROLL

See page 21, Sec. 1

ENGINEERING SOCIETIES EMPLOYMENT BUREAU

See page 13, Sec. 1